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ENV/CBC/EA(2021)2

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8 June 2021

ENVIRONMENT DIRECTORATE
CHEMICALS AND BIOTECHNOLOGY COMMITTEE

Working Party on Exposure Assessment

EMISSION SCENARIO DOCUMENT ON THE USE OF VAPOR DEGREASERS

Series on Emission Scenario Documents
No. 41

5th Meeting of the Working Party on Exposure Assessment
28-29 June 2021, Virtual Meeting

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JT03477787

Purpose and background

This OECD draft Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns, and potential release pathways of vapor degreasing chemicals. The document presents standard approaches for estimating environmental releases and occupational exposures.

This ESD may be periodically updated to reflect changes in the industry and new information available, and extended to cover the industry area in countries other than the lead (the United States). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Exposure Assessment (TFEA), which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (http://[HYPERLINK "http://www.oecd.org/env/riskassessment"]).

How to use this document

This document may be used to provide conservative, screening-level estimates of environmental releases of and occupational exposures to vapor degreasing chemicals. Some estimates might result in release and exposure amounts that are likely to be higher, or at least higher than average, than amounts that might actually occur in real world practice.

The users of this ESD should consider how the information contained in the document applies to the specific scenario being assessed. Where specific information is available, it should be used in lieu of the defaults presented in this document, as appropriate. All input values (default or chemical-specific) and the estimated results should be critically reviewed to assure their validity and appropriateness.

Coverage and methodology

The US Environmental Protection Agency (EPA) developed this ESD using relevant data[1] and available information on the solvent degreasing industry, including process descriptions, operating information, chemicals usage, wastes generation, worker activities, and

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[1] Please refer to Section 8 for a list of the specific references used in developing this methodology review draft.

exposure information. EPA supplemented the data collected with standard models[2] to develop the environmental release and occupational exposure estimates presented in this ESD.

This document is an update to EPA's draft Generic Scenario on the Use of Vapor Degreasers, dated September 2001. The primary sources of information cited in this ESD include industry-specific journal articles, EPA's 2006 Risk Assessment for the Halogenated Solvent Cleaning Source Category, various EPA and other government sources, and the U.S. Census Bureau's Economic Census. Additional information on the sources investigated and the references cited in this document are presented in Section 8.

The information in this document is based on US data. Certain aspects of the use of vapor degreasing chemicals may differ in other countries; therefore, alternate assumptions and parameters may be necessary in some applications of this emission scenario.

For the purpose of this document, a vapor degreasing chemical is defined as a chemical or a component chemical formulation used in vapor degreasing machines to clean oils and greases from substrates. The vapor degreasing chemical is typically the primary or secondary solvent, but may also be a stabilizer or additive in the degreasing formulation. The terms "vapor degreasing chemical" and "degreasing solvent" are used interchangeably in this document. The term "vapor degreaser" in this document is in reference to vapor degreasing machines/equipment. Based on the design of the operation, vapor degreasing chemicals are expected to be volatile liquids, with many chemicals having vapor pressure above 35 torr at room temperature.

The ESD covers the end use of vapor degreasing chemicals. The ESD does not cover the manufacture and processing (formulation) of the chemicals prior to end use; degreasing chemicals may be used neat, or as a component in a formulation in the vapor degreasing machine. An illustration of the scope of this document within the context of the life cycle of the chemical of interest is provided below.

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[2] EPA has developed a series of "standard" models for use in performing conservative release and exposure assessments in the absence of chemical- or industry-specific data. Several of these standard models will be described in Appendix B of the final ESD.
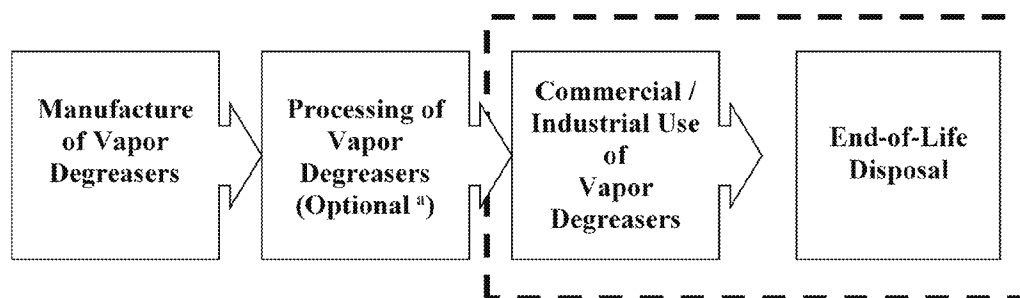
**Figure ES-[STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1].
Scope of Emission Scenario Document for the Use of Vapor
Degreasers**

a – Based on past PMN case search, vapor degreasing chemicals can be used neat (i.e., as the primary solvent), without processing or dilution.

Many of the chemicals covered in the ESD can also be used in other non-vapor phase cleaning applications, such as aerosol spray degreasing and cold cleaning. These other cleaning applications are not included in the scope of the ESD.

Due to the chemical's volatility, evaporative emissions (i.e., air releases) and inhalation exposures to vapor are expected to be the primary release and exposure. Where specific information on equipment design is not available, this document provides default values associated with those for an open-top vapor degreaser, as conservative. Release and exposure may be reduced if the degreasing machine is enclosed or equipped with a control technology (e.g., carbon adsorption).

The methods for estimating the following facility operating parameters, environmental releases, and occupational exposures are discussed in this ESD:

- ∞ Number of sites in the United States that are likely to have vapor degreasing operations;
- ∞ Number of operating days for the degreasing machines;
- ∞ Releases from unloading of transport container;
- ∞ Releases from the cleaning of transport containers;
- ∞ Releases during degreasing machine operation;
- ∞ Releases from equipment cleaning and waste solvent disposal;
- ∞ Number of workers involved in vapor degreasing operation;

∞ Dermal exposure to liquid during unloading of transport containers;

∞ Inhalation exposure to vapor during unloading of transport container;

∞ Dermal exposure to liquid during equipment cleaning and solvent changeout; and

∞ Inhalation exposure to vapor during vapor degreasing machine operation.

For highly volatile chemicals, exposure duration via the dermal route may be minimal as the chemical readily evaporates from the skin. However, dermal exposure may still be a significant exposure route if the chemical is quickly absorbed through the skin or if repeated contacts with the chemical occur.

How this document was developed

EPA, with support from Eastern Research Group, Inc. (ERG), has developed this ESD on the Use of Vapor Degreasers. The scope of the ESD is designed to serve the needs of both OECD programs as well as EPA. In the United States, EPA's Office of Pollution Prevention and Toxics (OPPT) is responsible for preparing occupational exposure and environmental release assessments of chemicals for a variety of programs under the Toxic Substances Control Act (TSCA), including Premanufacture Notice (PMN) reviews. While OECD ESDs traditionally focus on the potential releases of chemicals from industrial processes, this document also describes approaches for estimating potential occupational exposures to chemicals used for vapor degreasing applications. The occupational exposure methods are included so that the ESD may be used to fully support EPA's chemical review programs.

This document is published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.[SEQ CHAPTER \h \r 1]

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EMISSION SCENARIO DOCUMENT ON THE USE OF VAPOR DEGREASERS

1.0   Industry Summary and Background

Vapor degreasing is one of several degreasing options for removing oils, greases, lubricants, coolants, and resins from metal surfaces. In addition to cleaning metals, vapor degreasing can be used to clean non-porous materials that are compatible with solvents, such as glass, ceramics plastics, and elastomers (USEPA, 2001). It is an essential operation across a number of industries where surface cleaning is required.

The most widely used solvents for vapor degreasing have changed over the years. Until 1995, solvent usage for vapor degreasers was primarily 1,1,1 - trichloroethane (TCA) or trichloroethylene (TCE). In 1995, the U.S. government phased out production of TCA for being an ozone depleting substance. Today, chlorinated solvents such as TCE, perchloroethylene (PERC) and methylene chloride (MC) are most commonly used; these chemicals are clear, heavy liquids with excellent solvency and are virtually nonflammable. However, some companies have started to replace them with alternative solvents and solvent blends due to concerns for their hazard, safety, and the environment (Kanegsberg and Kanegsberg, 2011a).

1.1   Manufacturing and Formulation of Vapor Degreasing Chemicals

Vapor degreasing chemicals are manufactured as liquids. After manufacture, they could be used neat or could be further formulated. A typical vapor degreasing formulation contains more than 90 percent of the primary solvent and small amounts of secondary solvents and stabilizers. Formulators (i.e., solvent producers) may add organic stabilizers to chlorinated solvents to inhibit decomposition of the solvent from reaction with water, oxygen, or ultraviolet light (USEPA, 2001).

1.2   Use of Vapor Degreasing Chemicals

Vapor degreasing chemicals are supplied to the final use facilities as ready-to-use formulations. The use does not constitute a distinct industrial sector. Rather, it is an integral process in many metal and electronic industries where surface cleaning is required. For example, a facility that fabricates aircraft engine components may perform vapor degreasing to clean metal parts after shaping and machining (NIOSH, 1992a). A facility that manufactures electrolytic cells may perform vapor degreasing to clean and prepare the surface of anodes and cathodes prior to a coating process (NIOSH, 1994a). [REF _Ref462643672 \h] provides several examples of vapor degreasing across different industries.

Each final use facility may use one or more vapor degreasing machine(s) and chemical(s) depending on the facility throughput and the type of substrates being cleaned. For example, facilities that only perform occasional parts cleaning in their process operations may

use a small, batch vapor degreaser, while facilities that perform vapor degreasing on a regular basis may elect to use an in-line degreaser for increased throughput.

The degreasing process involves lowering the substrate to be cleaned into a solvent vapor zone. The hot solvent vapor condenses onto the cooler substrate, dissolving and removing organic contaminants on the substrate surface. In some processes, the substrate may be subsequently immersed into a solvent bath (with or without ultrasonics) for additional cleaning and washing. Vapor degreasing is particularly effective in cleaning substrates with recesses, blind holes, perforations, crevices, and welded seams (Kanegsberg and Kanegsberg, 2011a). The basic equipment design and chemical selection criteria are further discussed in Section [REF _Ref462644678 \r \h].
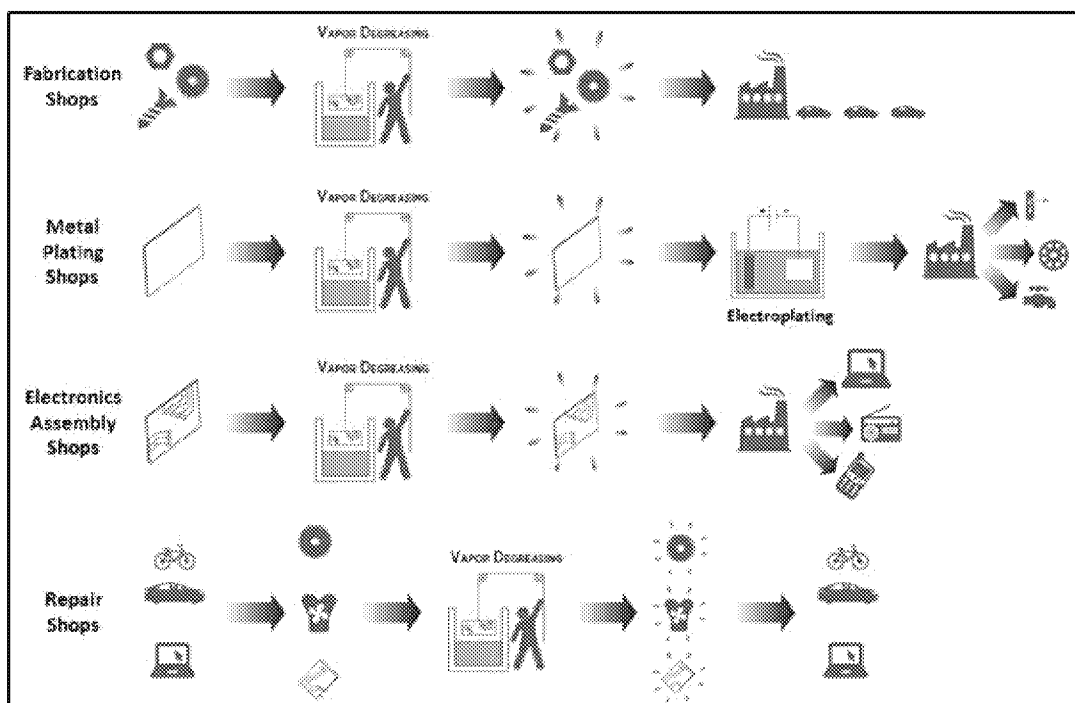

Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Use of Vapor Degreasing in a Variety of Industries

2.0   Process Description

Vapor degreasing is a popular cleaning method in the electronic and metal processing industries because it is effective in removing organics such as oils, greases, lubricants, coolants, and resins from crevices and hard to clean parts. It can be a critical cleaning step at some facilities, or it can be performed on an occasional, as-needed basis in others. The following describes the process operations that take place at an example facility performing vapor degreasing:

> *[Facility] manufactures hydraulic door closers and employs approximately 175 employees on two shifts. The processes at this facility includes the machining, cleaning, assembling, painting, packing, and shipping of hydraulic door closers. Most of the metal parts used in this operation are composed of aluminum and steel. The machine parts are cleaned in an aqueous cleaning solution prior to the assembly process. After final assembly, some of the parts are cleaned in a conveyorized vapor degreaser, which uses trichloroethylene. The assembled and cleaned parts are then conveyed to the paint room.. where a water-based primer and a water-based color coat [are spray applied]... (NIOSH, 1998)*

Vapor degreasing may take place in batches or as part of an in-line (i.e., continuous) system. In batch machines, each load (parts or baskets of parts) is loaded into the machine after the previous load is completed. With in-line systems, parts are continuously loaded into and through the degreasing machine. The selection of specific equipment will depend on several factors, including, but not limited to: degree of cleanliness required, type and shape of substrate to be cleaned, amount of workload, space, and costs (ASTM, 1989). For example, the amount of workload to be cleaned will dictate whether a laboratory-sized batch unit or an in-line, conveyorized equipment is used. The shape, form, and size of substrate to be cleaned may dictate whether a vapor only, or a spray-vapor cycle is required. Batch and in-line systems are further described below.

2.1   Batch Systems

2.1.1   *Open-Top Vapor Degreasers (OTVD)*

The traditional batch degreaser is a tank with cooling coils and a cover at the top. [REF _Ref480366183 \h * MERGEFORMAT][REF _Ref430614525 \h] is a diagram of an OTVD. Heating elements at the bottom of the degreaser heat the liquid solvent to above its boiling point. Solvent vapor rises to the height of the chilled condensing coils on the inside walls of the unit, producing a hot vapor zone below the coils. The condensing coils cool the vapor, causing it to condense and return to the bottom of the degreaser (USEPA, 2006a).

To clean dirty parts, the substrates are lowered into the vapor zone. The hot vapor condenses onto the substrate, which is cooler in temperature, and the condensation dissolves the grease and carries it off the substrate surface as it drains into the solvent reservoir below. The process continues until the substrate temperature reaches that of the vapor, at which point the vapor stops condensing (determined by visual inspection to verify the substrate is dry) and the cleaned and dried substrate is lifted out of the vapor zone. The degreaser can also contain one or more immersion tanks below the vapor zone for additional cleaning and rinsing, either before or after vapor-phase cleaning. Transducers can also be installed to provide ultrasonic cleaning action to remove heavy oil deposits and solid soils (Kanegsberg and Kanegsberg, 2011a).

As degreasing occurs, sludge consisting of oils, greases, and other impurities build up in the degreasing solvent. To prevent overheating or igniting of the sludge, the solvent needs to be replaced and sludge cleaned from the degreaser periodically (GAPS, 2015). This cleaning process should occur when the solvent boiling point exceeds the maximum recommended operating temperature or when the oil content reaches 25 percent by volume for chlorinated solvents (GAPS, 2015).
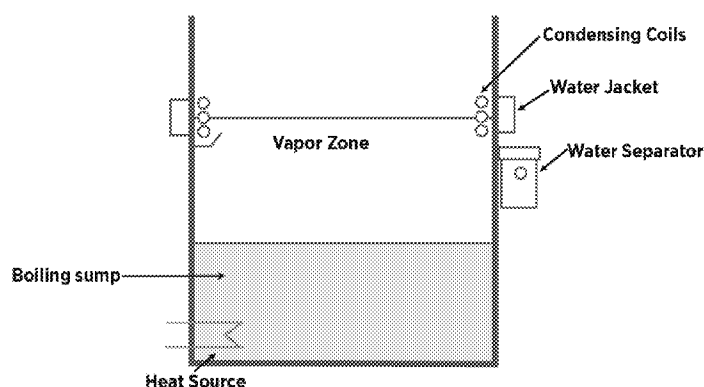

Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Open Top Vapor Degreaser

2.1.2   *Open-Top Vapor Degreasers (OTVD) with Enclosure*

OTVDs with enclosures operate the same as standard OTVDs except that the OTVD is enclosed on all sides during degreasing. The enclosure is opened and closed to add or remove parts to/from the machine, and solvent is exposed to the air when the cover is open. Enclosed OTVDs may be vented directly to the atmosphere or first vented to an external carbon filter and then to the atmosphere (EPA, 2004). [REF _Ref476663889 \h * MERGEFORMAT] illustrates an OTVD with an enclosure. The dotted lines in the figure represent the optional carbon filter that may or may not be used with an enclosed OTVD.
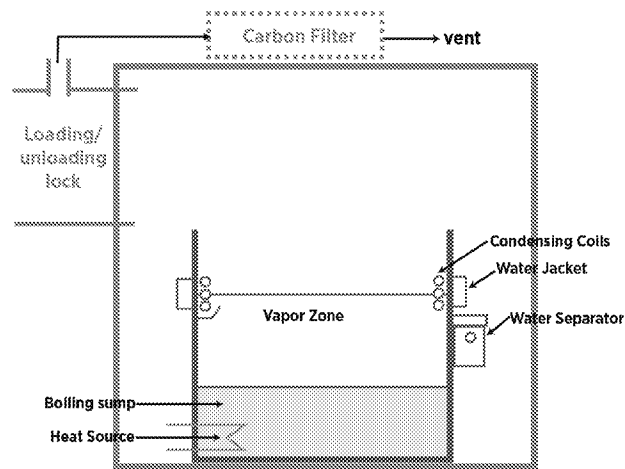
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Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Open Top Vapor Degreaser with Enclosure

2.1.3   *Closed-Loop Degreasers (Airtight)*

In closed-loop degreasers, parts are placed into a basket, which is then placed into an airtight work chamber. The door is closed and solvent vapors are sprayed onto the parts. Solvent can also be introduced to the parts as a liquid spray or liquid immersion. When cleaning is complete, vapors are exhausted from the chamber and circulated over a cooling coil where the vapors are condensed and recovered. The parts are dried by forced hot air. Air is circulated through the chamber and residual solvent vapors are captured by carbon adsorption. The door is opened when the residual solvent vapor concentration has reached a specified level (Kanegsberg and Kanegsberg, 2011b). [REF _Ref476663974 \h * MERGEFORMAT] illustrates a standard closed-loop vapor degreasing system.
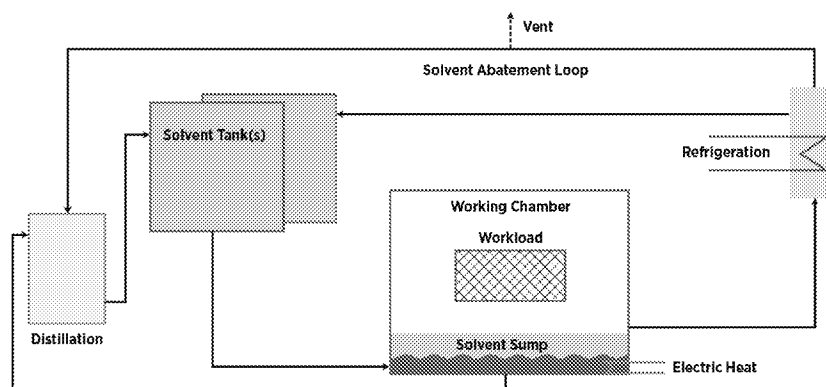
Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Closed-loop/Vacuum Vapor Degreaser

2.1.4 *Airless Degreasers (Vacuum Drying)*

Airless degreasing systems are also sealed, closed-loop systems, but remove air at some point in the degreasing process. Removing air typically takes the form of drawing vacuum, but could also include purging air with nitrogen at some point of the process (in contrast to drawing vacuum, a nitrogen purge operates at a slightly positive pressure). In airless degreasing systems with vacuum drying only, the cleaning stage works similarly as with the airtight closed-loop degreaser. However, a vacuum is generated during the drying stage, typically below 5 torr (5 mmHg). The vacuum dries the parts and a vapor recovery system captures the vapors (Kanegsberg and Kanegsberg, 2011b; EPA, 2001a; NEWMOA, 2001).

2.1.5 *Airless Vacuum-to-Vacuum Degreasers*

Airless vacuum-to-vacuum degreasers are true "airless" systems because the entire cycle is operated under vacuum. Typically, parts are placed into the chamber, the chamber sealed, and then vacuum drawn within the chamber. The typical solvent cleaning process is a hot solvent vapor spray. The introduction of vapors in the vacuum chamber raises the pressure in the chamber. The parts are dried by again drawing vacuum in the chamber. Solvent vapors are recovered through compression and cooling. An air purge then purges residual vapors over an optional carbon adsorber and through a vent. Air is then introduced in the chamber to return the chamber to atmospheric pressure before the chamber is opened (Durkee, 2014; NEWMOA, 2001). This type of system was reported to emit less than 1 gal/month of solvent vapor. Users of these systems have also reported using the equipment for over five years without solvent changeout (Kanegsberg and Kanegsberg, 2011a).

The general design of vacuum vapor degreasers and airless vacuum degreasers is similar as illustrated in [REF _Ref476663974 \h * MERGEFORMAT] for closed-loop systems except that the work chamber is under vacuum during various stages of the cleaning process.

2.2   In-Line Systems

In-line systems covers conveyorized degreasers and web cleaners. Conveyorized degreasers are solvent cleaning machines that use an automated parts handling system, typically a conveyor, to automatically provide a continuous supply of parts to be cleaned. They are usually fully enclosed except for the conveyor inlet and outlet portals. Conveyorized degreasers are likely used in similar shop types as batch vapor degreasers except for repair shops, where the number of parts being cleaned is likely not large enough to warrant the use of a conveyorized system. There are seven major types of conveyorized degreasers: monorail degreasers; cross-rod degreasers; vibra degreasers; ferris wheel degreasers; belt degreasers; strip degreasers; and circuit board degreasers (USEPA, 1977).

Continuous web cleaning machines differ from typical conveyorized degreasers in that they are specifically designed for cleaning parts that are coiled or on spools such as films, wires, and metal strips (Kanegsberg and Kanegsberg, 2011a). The following subsections describe the various types of conveyorized and web degreasers.

2.2.1   *Monorail Degreaser*

Monorail cleaning systems, shown in [REF _Ref462646006 \h * MERGEFORMAT], are typically used when parts are already being transported throughout the manufacturing areas by a conveyor (USEPA, 1977). It is most useful for automatic cleaning via solvent spray or vapor (Morrison and Murphy, 2013; USEPA, 1977). They use a straight-line conveyor to transport parts into the cleaning zone and back out (Morrison and Murphy, 2013). The parts may enter one side and exit and the other or may make a 180° turn and exit through a tunnel parallel to the entrance (USEPA, 1977).
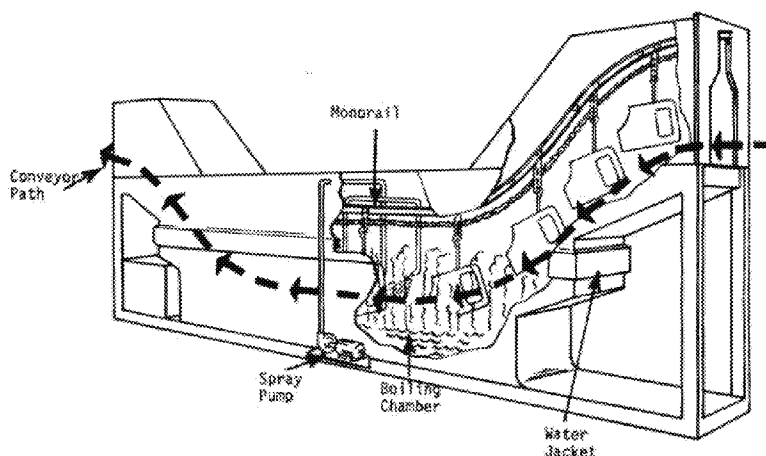
**Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1].
Monorail Conveyorized Degreaser (USEPA, 1977)**

2.2.2   *Cross-Rod Degreaser*

Cross-rod cleaning machines, shown in [REF _Ref462646411 \h * MERGEFORMAT], utilize two parallel chains connected by a rod that support the parts throughout the cleaning process (Morrison and Murphy, 2006; USEPA, 1977). The parts are usually loaded into perforated baskets or cylinders and then transported through the machine by the chain support system. The baskets and cylinders are loaded and unloaded manually (USEPA, 1977). Cylinders are used for small parts or parts that need enhanced solvent drainage because of crevices and cavities. The cylinders allow the parts to be tumbled during cleaning and drying and thus increase cleaning and drying efficiency (Morrison and Murphy, 2006; USEPA, 1977).
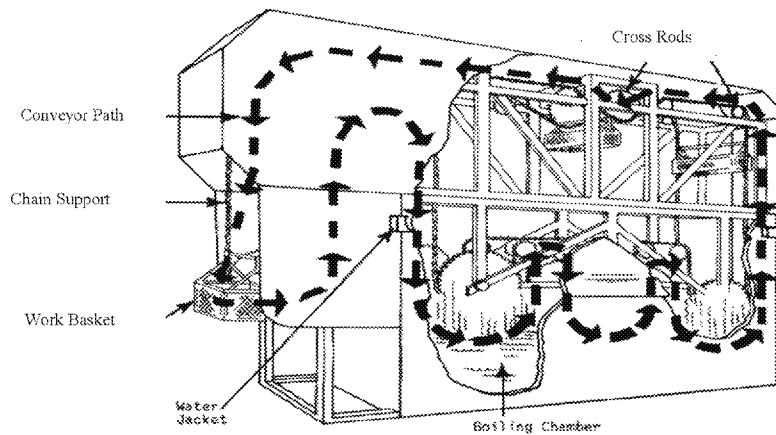
Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Cross-Rod Conveyorized Degreaser (USEPA, 1977)

2.2.3   *Vibra Degreaser*

Vibra cleaning machines ([REF _Ref462669763 \h * MERGEFORMAT]) have parts fed through a chute that leads to a pan flooded with solvent in the cleaning zone. The pan is connected to a spiral elevator, which are both vibrated continuously throughout the cleaning process. The vibrations cause the parts to travel up the elevator, where the solvent condenses and drying occurs, and eventually out of the machine. The vibrations cause the machine to be very loud and therefore engineering controls must be used to reduce the noise when operating these machines (Morrison and Murphy, 2006; USEPA, 1977).
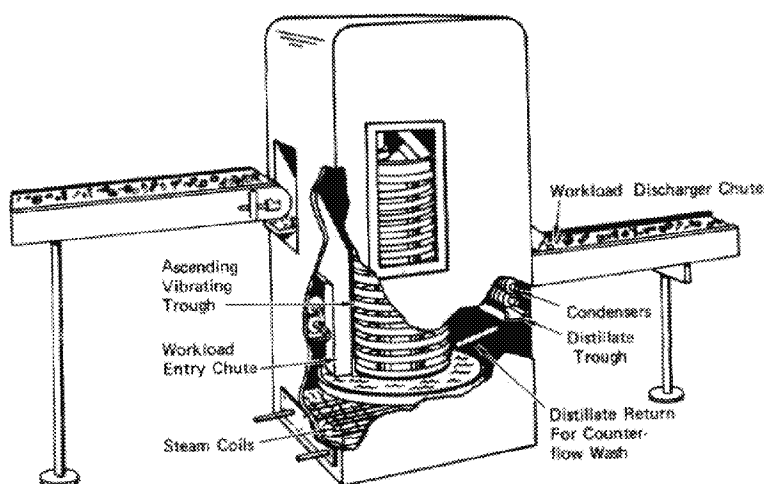
Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Vibra Conveyorized Degreaser (USEPA, 1977)

2.2.4   *Ferris Wheel Degreaser*

Ferris wheel cleaning systems ([REF _Ref462646703 \h * MERGEFORMAT]) are generally the smallest of all the conveyorized degreasers (USEPA, 1977). In these systems, parts are manually loaded into perforated baskets or cylinders and then rotated vertically through the cleaning zone and back out (Morrison and Murphy, 2013).
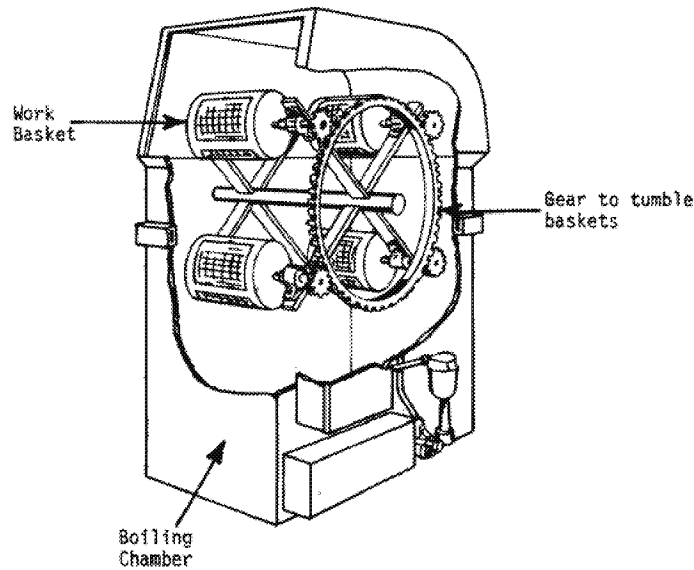
Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Ferris Wheel Conveyorized Degreaser (USEPA, 1977)

2.2.5   *Belt Degreaser*

Belt degreaser cleaning systems ([REF _Ref462647514 \h * MERGEFORMAT] and [REF _Ref462647516 \h * MERGEFORMAT]) are used when simple and rapid loading and unloading of parts is desired. Parts are loaded onto a mesh conveyor belt that transports them through the cleaning zone and out the other side (EPA, 1977).

2.2.6   *Strip Degreaser*

Strip degreaser cleaning machines ([REF _Ref462647514 \h * MERGEFORMAT]) are exactly the same as belt degreasers except that the belt itself is being cleaned rather than parts being loaded onto the belt for cleaning (EPA, 1977).
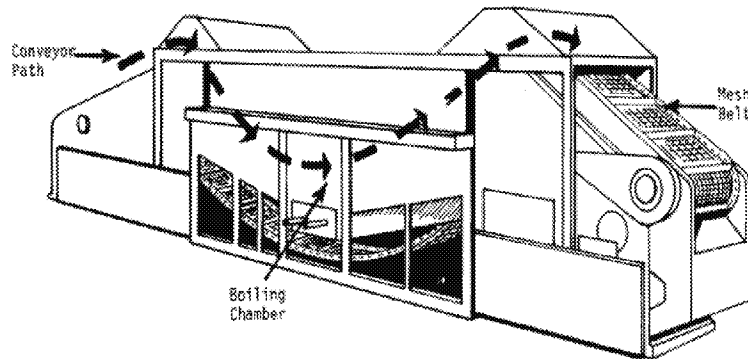
**Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1].
Belt/Strip Conveyorized Degreaser (USEPA, 1977)**
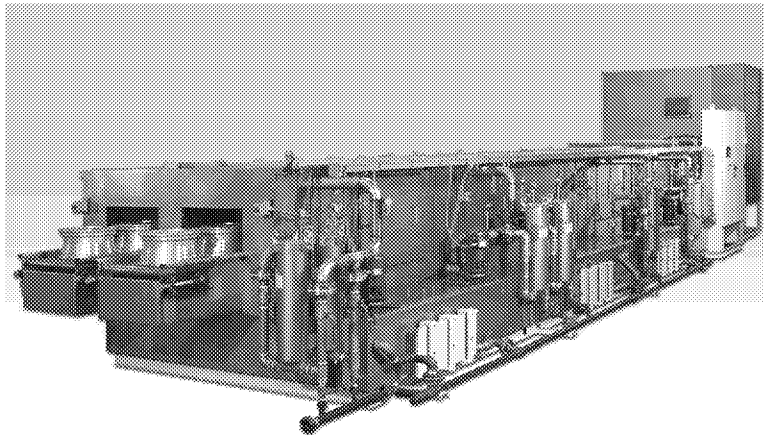
**Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Belt
Conveyorized Degreaser (Jenfab Aqueous Cleaning Systems, 2015)**

2.2.7   *Circuit Board Degreasers*

Circuit Board Degreasers use any of the above conveyorized designs. However, parts are cleaned in three different steps due to the manufacturing processes involved in circuit board production (USEPA, 1977).

2.2.8 *Continuous Web Cleaning Machines*

Continuous web cleaning machines ([REF _Ref462647728 \h * MERGEFORMAT]) are considered to be a subset of in-line cleaning machines and operate under the same general principles: there is a continuous supply of parts to be cleaned. Continuous web cleaning machines differ from typical conveyorized degreasers in that they are specifically designed for cleaning films, coils, wires, and metal strips. The parts are cleaned at speeds in excess of 11 ft/min and generally entered uncoiled such that the same part is simultaneously entering and exiting the liquid or vapor cleaning zone. The parts are then recoiled or cut (FL DEP). The parts are typically loaded onto rollers that transport the parts through the cleaning zone. The rollers vary in size depending on the type of parts being cleaned. Many continuous web cleaning machines incorporate air knives to improve drying (Kanegsberg and Kanegsberg, 2011a).
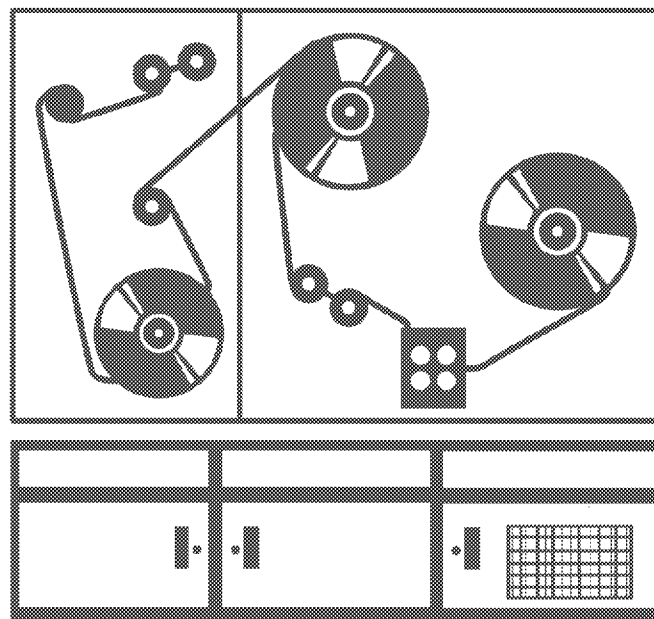
**Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1].
Continuous Web Cleaning Machine**

2.3   Types of Chemicals

Historically, chlorinated solvents such as TCE, PERC, and methylene chloride have been the standard for vapor phase cleaning. These chemicals are clear, heavy liquids with excellent solvency, and are virtually nonflammable since they have no flash point as determined by standard test methods. In recent years, a number of new solvents have become available. [REF _Ref425510835 \h] provides a list of available solvents on the market that are acceptable vapor degreasing chemicals. In addition to the list, several manufacturers supply solvent blends for specific purposes. For example, hydrofluorocarbon (HFC) and hydrofluoroether (HFE) can be blended with trans-1,2,-dichloroethylene to provide additional solvency. In addition, some of these solvents can be mixed to form an azeotrope such that once mixed, stay together in the same ratio throughout boiling, rinsing, and vapor degreasing phases (Kanegsberg and Kanegsberg, 2011a).

Chemical and physical properties are important considerations when choosing a vapor degreasing chemical for the metal cleaning operation. For example, chemicals with lower boiling point (e.g., methylene chloride) are suitable for cleaning temperature-sensitive parts such as thermal switches or thermometers. The Kauri-butanol (KB) value is a rough measure of solvency power. Chemicals with higher KB-value are more effective in removing heavy organics such as oils and greases, while those with lower KB-value are used in critical cleaning where particle removal and light organics are found. Vapor density is a measure of the weight of the vapor to air. Any chemical selected as a vapor degreasing solvent should be heavier than air to minimize emissions from the degreasing machine (Kanegsberg and Kanegsberg, 2011a).

Based on the design of the operation, vapor degreasing chemicals are expected to have high volatility, with many chemicals having vapor pressure above 35 mm Hg at room temperature (i.e., highly volatile).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Physical Properties of Commercially Available Vapor Degreasing Solvent

Chemical	Kauri-Butanol Value	Boiling Point (°C)	Relative Vapor Density (air = 1)	Vapor Pressure at 25°C (mm Hg)
Trichloroethylene (TCE)	129	87	4.53	70
Perchloroethylene (PERC)	90	121	5.76	20
Methylene chloride (MC)	136	39.8	2.93	350
n-Propyl bromide (n-PB or 1-BP)	125	71	4.25	111
HCFC (AK-225 AES)	41	52	7	291
HFC (Vertrel XP)	9.4	52	7.86	253
HFE-71IPA	10	54.8	7.51	207
Acetone	NA	56	2	229
Cyclohexane	58	80.7	2.9	95
Isopropyl alcohol	NA	82	2.1	40
N-methyl pyrrolidone (NMP)	350	204.3	3.4	0.24
p-Limonene	67	154	4.73	2
Trans-1,2-dichloroethylene	117	47.8	3.34	330

Source: (Kanegsberg and Kanegsberg, 2011a)

2.4 Release and Exposure Considerations

[REF _Ref461778940 \h * MERGEFORMAT] illustrates the typical release and exposure sources from vapor degreasing operation. For OTVDs, which are batch systems, releases during degreaser operation can occur from solvent dragout or vapor displacement when the substrates to be cleaned are raised out of or lowered into the equipment (Kanegsberg and Kanegsberg, 2011c). For in-line degreasers, emission points may be limited to the conveyor

inlet and outlet portals, if the system is fully enclosed. Additional releases can occur from charging of solvent (degreasing chemical) and disposal of spent solvent.

Similarly, worker exposure can occur while charging the degreasing chemical, cleaning the degreasing machine (i.e., disposing spent solvent), and working in a surrounding area while the machine is in operation. Inhalation exposure to vapor is expected to be the primary exposure route. Dermal exposure to liquid may also occur while handling degreasing chemicals; however, the duration of exposure may be limited for highly volatile chemicals that quickly evaporates from the skin.
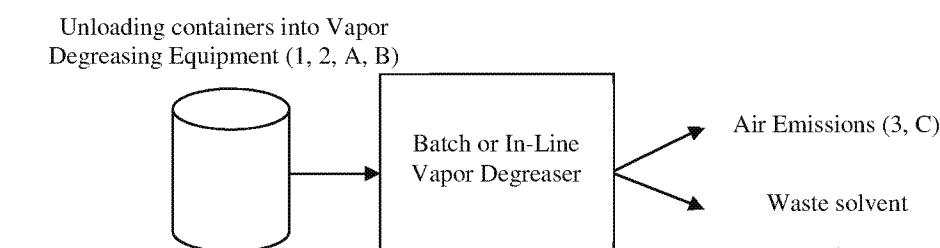
Environmental Releases:

1. Release to air from unloading container into vapor degreasing equipment.

2. Release to uncertain media from cleaning of transport container.

3. Release to air during vapor degreasing operation (including release to air during cleaning activities).

4. Release to water from vapor degreasing wastewater

5. Release to incineration from equipment cleaning and waste solvent disposal.

Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Typical Release and Exposure Points during the Use of Vapor Degreasing Chemicals

3.0 Overall Approach and General Facility Estimates

This ESD presents EPA's standard approach for estimating environmental releases of and occupational exposures to vapor degreasing chemicals.

This section of the ESD presents general facility calculations for facilities performing vapor degreasing operations, which include estimates of the daily use rates of vapor degreasing chemicals, the number of facilities performing vapor degreasing operations, and the number of operating days at these facilities.

Section 4 of the ESD presents environmental release assessments from the use of vapor degreasing chemicals. This section utilizes the general facility estimates to determine the quantity of chemical released from various points at the facilities performing vapor degreasing operations and the most likely media of release for each source.

Section 5 of the ESD presents occupational exposure assessments. Because vapor degreasing chemicals are expected to be volatile, inhalation is expected to be primary route of exposure.

3.1 Introduction to the General Facility Estimates

Through the remainder of this section, EPA utilized available industry and U.S. National Emissions Inventory (NEI) data to estimate the number of facilities that perform vapor degreasing operations in the U.S. For the purpose of this document, the term "facility" and "site" is used interchangeably. According to 2017 NEI data, metal degreasing operations are often conducted at facilities that fall within NAICS 331 through 336, including facilities that have primary metal manufacturing, fabricated metal product manufacturing, machinery manufacturing, computer and electronic manufacturing, and transportation equipment manufacturing.

This section also describes the methods used and the assumptions made to estimate the use rate for a vapor degreasing chemical and the number of transport containers used annually to transfer a potential chemical of interest. [REF _Ref462650419 \h] summarizes the general facility estimates and the ESD section in which they are discussed.

**Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary
of General Facility Parameters**

Parameter	Description	ESD Section
$TIME_{operating\_days}$	Number of operating days at a facility that performs vapor degreasing operation (days/yr)	3.3
F_{chem}	Concentration of vapor degreasing chemical as received at the final use facilities (kg chemical/kg formulation)	3.4
$Q_{chem\_site\_yr}$	Annual use rate of vapor degreasing chemical (kg/site-yr)	3.5
$Q_{chem\_site\_day}$	Daily use rate of vapor degreasing chemical (kg/site-day)	3.6
N_{sites}	Number of sites using the vapor degreasing chemical (sites)	3.7
$N_{container\_unload\_site\_yr}$	Number of transport containers unloaded at each site per year (containers/site-yr)	3.8

3.2   Type of Degreasing Machine

The selection of the specific type of degreasing equipment will depend on several factors, including, but not limited to: type, size, and shape of substrate to be cleaned, type and amount of soils to be removed, degree of cleanliness required, amount of workload, space, and costs (ASTM, 1989). For example, the amount of workload to be cleaned will dictate whether a laboratory-sized batch unit or an in-line, conveyorized equipment is used. The shape, form, and size of substrate to be cleaned may dictate whether a vapor only, or a spray-vapor cycle is required.

The aim of this section is to utilize available industry-specific information and data to the greatest extent possible in developing any estimation method. If the type of vapor degreasing machine is known, data for those machines presented in this ESD should be used in Sections 3, 4, and 5. However, where information is not available to distinguish the type of vapor degreasing machine, an **open-top vapor degreaser (OTVD) machine should be assumed.** OTVDs are expected to have the highest evaporative losses during degreasing operation. This default assumption will provide conservative, screening-level estimates of release and occupational exposure. The default values cited throughout this document are intended to be used only when appropriate site-specific or chemical-specific information is not available.

3.3   Days of Operation (TIME$_{operating\_days}$)

[REF _Ref461790171 \h * MERGEFORMAT] presents the typical operating schedule for vapor degreasing machines, broken down by type of industry. The data were obtained through an analysis of actual equipment operating schedules reported to the 2017 National Emissions Inventory (NEI). Data for the most common NAICS codes in the 2017 NEI dataset for degreasing operations are presented separately in [REF _Ref461790171 \h * MERGEFORMAT], with data for additional NAICS codes aggregated. According to 2017 NEI data, the number of operating days for facilities that infrequently conduct vapor degreasing is 1 – 15 days (based on the minimum); however, the majority of facilities (over 95%), report vapor degreasing occurring more frequently.

As shown in [REF _Ref461790171 \h * MERGEFORMAT], OTVDs typically operate 296 days per year and conveyorized degreasers typically operate 260 days per year. The data suggests that web cleaning machines operate 320 days per year on average; however, only four data points are available for this subcategory. If the type of degreasing machine and industry in which the chemical is used is known, the appropriate number of days per year should be selected from [REF _Ref461790171 \h * MERGEFORMAT]. In lieu of chemical-specific information, EPA recommends assuming **296 days per year operation** as default for OTVDs (USEPA, 2017).[3]

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Reported Vapor Degreaser Operating Days per Year in the 2017 NEI

Industry	Reported Days per Year					
	Open-top Vapor Degreaser (OTVD)[a]		Conveyorized Degreaser[b]		Web Cleaner[c]	
	Mean	Median	Mean	Median	Mean	Median
Primary Metal Manufacturing (NAICS 331)	278	330	248	364	364	364
Fabricated Metal Product Manufacturing (NAICS 332)	297	312	204	156	n/a	n/a
Machinery Manufacturing (NAICS 333)	268	252	n/a	n/a	275	275

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[3] Note: If it is known that the facility infrequently conducts vapor degreasing operations, EPA recommends using 15 days/yr for TIME$_{operating\_days}$, which is based on the upper end of the range of minimum operating days reported in 2017 NEI for degreasing operations. Otherwise, EPA recommends the default of 296 days/year.

Computer and Electronic Product Manufacturing (NAICS 334)	259	260	312	312	n/a	n/a
Transportation Equipment Manufacturing (NAICS 336)	313	364	298	260	n/a	n/a
Other (All other NAICS codes) d	277	260	342	350	n/a	n/a
All (All NAICS codes) e	286	**296** (default)	269	**260**	320	**320**

n/a – not applicable because no data available

a – There are 173 records of operating data for OTVDs in the 2017 NEI.

b – There are 19 records of operating data for conveyorized vapor degreaser in the 2017 NEI.

c – There are 4 data points from 2 unique facilities in the 2017 NEI for web cleaner/degreaser.

d – Other NAICS codes excluding 331, 332, 333, 334, and 336.

e – All NAICS codes, including 331, 332, 333, 334, and 336.

Source: (USEPA, 2017)

3.4 Physical Form and Concentration of Vapor Degreasing Chemical (F_{chem})

The majority of vapor degreasing chemicals are supplied to end use facilities as neat liquids[4]. In some cases, these chemicals may also be supplied as part of a formulation (i.e., solvent blends). [REF _Ref462759679 \h] provides information on the typical concentration of vapor degreasing formulations. Where chemical-specific information on the physical form and concentration is not available, EPA recommends assuming the chemical is the primary solvent at **100 percent concentration (i.e., neat liquid)** as supplied and used in the vapor degreasing machine.

**Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1].
Composition of Vapor Degreasing Chemicals**

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[4] In pre-manufacture notices submitted from 1999 to 2015 under EPA's New Chemicals Programs, 80 percent of submissions indicate the vapor degreasing chemical is supplied as a neat liquid.

Component	Weight %	
	Range	Typical
Primary Solvent*	80-99	>90
Stabilizer	0.05-0.25	0.15
Secondary Solvents (each)	1-10	<2

Source: DuPont Technical Info, 2000 and Petroferm Technical Datasheets, 2001, as referenced in (USEPA, 2001).

Note: The composition provided in the table is consistent with Jones and Nicas, which reported a single component ranging from 2.5 to 96.5 percent in the formulation (Jones and Nicas, 2005).

3.5 Annual Use Rate of Vapor Degreasing Chemical ($Q_{chem\_site\_yr}$)

EPA's 2006 residual risk analysis for the National Emission Standard for Hazardous Air Pollutants (NESHAP) for halogenated solvent cleaning machines contains solvent use rate data collected in maximum achievable control technology (MACT)[5] compliance reports submitted to states and EPA regions. The data include solvent consumption at 96 facilities pre- and post-MACT implementation, covering a wide range of industry sectors including defense, aerospace, metal plating and processing, semiconductor, and electronics. Of the facilities, 78 perform vapor-phase degreasing; 62 of the 78 facilities (79 percent) have only one machine (see [REF _Ref480707292 \h]).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Number of Vapor Degreasing Machines per Facility

Number of Facility with Vapor Degreasing Machine	Number of Machine per Facility			
	Minimum	Maximum	Average	Median
78	1	7	1.4	1

Source: (USEPA, 2006a)

*Includes batch vapor, batch closed loop, in-line, and vapor web machines.

[REF _Ref480707602 \h] presents the estimated machine-level annual solvent use rate for batch and in-line vapor degreasing machines. These use rates represent the makeup

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[5] The MACT standards were promulgated in 1994 under 40 CFR Part 63, Subpart T. The provisions apply to individual cleaning machines using specific halogenated solvents. Each owner or operator subject to these provisions shall comply with the specified requirements.

solvent rate, i.e., amount of solvent added on an annual basis. As default, this ESD assumes each facility has only one machine and that the machine-level use rate equals the facility-level use rate. Solvent use rates are available for three categories of vapor degreasing machines: batch, in-line, and closed-loop. The MACT document defines closed-loop cleaning system as a subset of batch cleaner with a closed system capable of reusing solvent. Compared to regular batch machines, closed-loop machines have a substantially lower solvent use rate, likely due to the machine's reduced solvent loss during operation.

For batch vapor degreasers, the data suggests a reduction in the average solvent use rate after MACT implementation. In the post-MACT scenario, the overall emissions are reduced due to presence of control equipment, thereby reducing the amount of makeup solvent needed. There is insufficient data for in-line systems to provide an accurate comparison of pre- and post-MACT solvent use rate.

While post-MACT data are likely more representative of chemicals that are a hazardous air pollutant (HAP), or chemicals that are used in existing MACT-compliant machines, pre-MACT data may be representative of use rate for new chemicals not currently subject to the NESHAP. Users of the ESD should refer to the decision logic in [REF _Ref480711629 \h] to determine whether pre- or post-MACT solvent use rate data may be more appropriate for the chemical of interest. Where chemical-specific information is not available, EPA recommends assuming the median (i.e., 50th percentile value) use rate for batch systems, or **2,083 kg/site-yr** as default to estimate annual facility-level use rate.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Annual Machine-level Solvent Use Rate

Machine Type	Solvent Use Rate (kg/yr) [a]					No. Data Points
	Min	Max	Average	50th %-tile	95th %-tile	
Pre-MACT						
Batch [b]	272	23,950	7,580	4,990	20,556	9
Batch, Closed Loop	Not applicable					
In-Line [c]	2,702	2,702	2,702	2,702	2,702	1
Post-MACT						
Batch [b]	78	79,120	6,072	2,083 (default)	25,852	45
Batch, Closed Loop	28	778	403	403	740	2

Machine Type	Solvent Use Rate (kg/yr) [a]					No. Data Points
	Min	Max	Average	50th %-tile	95th %-tile	
In-Line [c]	9,281	26,943	18,112	18,112	26,060	2

Source: (USEPA, 2006a)

a – Represents the use rate for a single solvent; data are for facility-level use rate of trichloroethylene, methylene chloride, perchloroethylene, or 1,1,1-trichloroethane.

b – Batch vapor degreaser.

c – The source document did not specify whether in-line machines involve vapor- or liquid-phase cleaning.
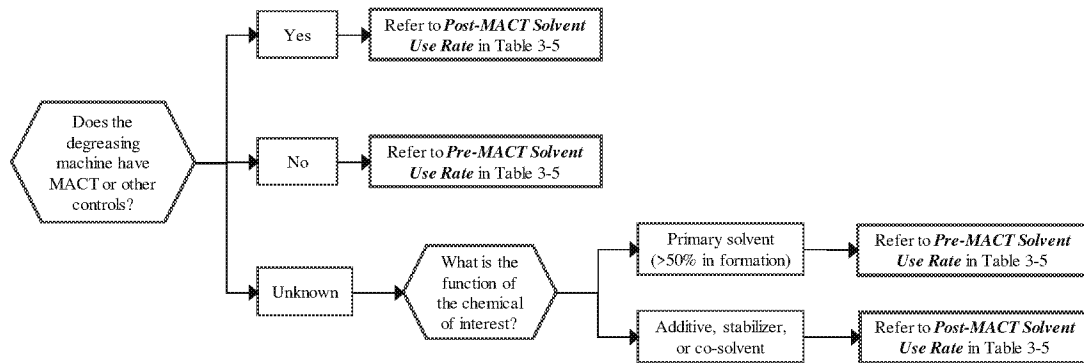
Figure [STYLEREF 1 \s]-[SEQ Figure * ARABIC \s 1]. Logic Diagram for Determining Solvent Use Rate

3.6   Daily Use Rate of Vapor Degreasing Chemical ($Q_{chem\_site\_day}$)

        As shown in [REF _Ref461803028 \h], the annual and daily use rate of a vapor degreasing chemical depends on the type of degreasing machine and the scale of operation at the final use facility. Based on the annual use rates shown above ($Q_{chem\_site\_yr}$), the daily use rate of a vapor degreasing chemical can be calculated using the following equation:

$$Q_{chem\_site\_day} = \frac{Q_{chem\_site\_yr}}{TIME_{operating\_days}} \qquad (3\text{-}1)$$

Where:

$Q_{chem\_site\_day}$ = Daily use rate of vapor degreasing chemical (kg/site-day)

$Q_{chem\_site\_yr}$ = Annual use rate of vapor degreasing chemical (Default value: 2,083 kg/site-yr)

$TIME_{operating\_day}$= Number of operating days for the degreasing machine (Default: 296 days/yr)

Because this parameter is highly process dependent, estimates for the daily use rate should always be made on a case-specific basis when possible. When information is not readily available, an OTVD should be assumed as default to provide a more conservative release and exposure assessment.

3.7 Number of Sites (N_{sites})

The number of facilities using the chemical of interest (N_{sites}) depends on the total annual production of the chemical of interest (Q_{chem_yr}), the daily use rate of the chemical of interest ($Q_{chem\_site\_day}$), and the annual operating days ($TIME_{operating\_days}$). Equation 3-2 demonstrates how the number of facilities performing vapor degreasing operations using a chemical of interest could be determined.

$$N_{sites} = \frac{Q_{chem\_yr}}{Q_{chem\_site\_day} \times TIME_{operating\_days}} \qquad (3\text{-}2)$$

Where:

N_{sites}[6] = Number of sites using the vapor degreasing chemical (sites)

Q_{chem_yr} = Annual production volume of vapor degreasing chemical (kg chemical/yr)

$Q_{chem\_site\_day}$ = Daily use rate of vapor degreasing chemical (kg chemical/site-day) (see Equation 3-1)

$TIME_{operating\_days}$= Number of operating days for degreasing machines (days/yr) (Default: 296 days/yr)

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[6]The value for N_{sites}, calculated using Equation 3-2 should be rounded up to the nearest integer value. $Q_{chem\_site\_day}$ should then be adjusted for the N_{sites} integer value (to avoid errors due to rounding):

$$Q_{chem\_site\_day} = \frac{Q_{chem\_yr}}{N_{sites} \times TIME_{operating\_days}}$$

Note: If the number of sites is known, the previous equation may also be used to estimate the resulting average annual production rate for use in subsequent calculations.

Note that the calculated value of N_{sites} should not exceed the total number of facilities performing vapor degreasing operations known to operate in the United States. The 2006 NESHAP document estimated 3,800 cleaning machines located at 1,900 facilities in the U.S. based on 1998 ICR data (USEPA, 2006a). As discussed in Section [REF _Ref61954277 \n \h], EPA estimated approximately 112,701 facilities; however, this value is likely an overestimate because it is based on NAICS industry codes for metal processing operations, which may not all have degreasing operations. The true number of degreasing facilities likely falls between the 1998 ICR estimate of 1,900 sites and 112,701 sites; however, since this value is unknown, the calculated value for N_{sites} should not exceed 112,701.

Summary of the Relationship of General Facility Parameters

The values for days of operation ($TIME_{operating\_days}$), daily use rate of the chemical of interest ($Q_{chem\_site\_day}$), and number of sites (N_{sites}) are related. This ESD presents one method for estimating N_{sites} using estimated default values for: 1) the annual production quantity of a vapor degreasing chemical; 2) the total number of operating days per year at the final use site; 3) the mass fraction of the chemical in the transport container; and 4) the daily use rate of a vapor degreasing chemical at a single site.

If N_{sites} and $TIME_{operating\_days}$ are known, $Q_{chem\_site\_day}$ can be calculated directly without using Equation 3-2. This alternative calculation is:

$$Q_{chem\_site\_day} = \frac{Q_{chem\_yr}}{N_{sites} \times TIME_{operating\_days}}$$

3.8 Number of Transport Containers Unloaded per Site ($N_{container\_unload\_site\_yr}$)

Vapor degreasing chemicals can be supplied in a variety of container sizes, typically ranging from 1- to 55-gallon containers (Gallade Chemical, 2016; Tech Spray, 2016). The distribution of container type and sizes is not known, but EPA recommends **assuming chemicals are supplied in 55-gallon drums** where information is not available. The number of transport containers unloaded annually per site can be estimated based on the daily use rate, container size, and the purity of the precursor.

$$N_{container\_unload\_site\_yr} = \frac{Q_{chem\_site\_day} \times TIME_{operating\_days}}{F_{chem} \times V_{container} \times \rho_{formulation} \times 3.785 \frac{L}{gal}} \qquad (3\text{-}3)$$

Where:

$N_{container\_unload\_site\_yr}$	$=$	Number of transport containers unloaded at each site per year (containers/site-yr)
$Q_{chem\_site\_day}$	$=$	Daily use rate of vapor degreasing chemical (kg/site-day)
F_{chem}	$=$	Weight fraction of vapor degreasing chemical in the formulation as received (Default: 1 kg chemical/kg formulation)
$TIME_{operating\_days}$	$=$	Number of operating days (days/yr) (Default: 296 days/yr)
$V_{container}$	$=$	Volume of transport container (Default: 55-gallon drums)
$\rho_{formulation}$	$=$	Density of chemical formulation (kg/L formulation; Default: 1 kg/L)

4.0 Environmental Release Assessments

This section presents an approach to quantify the releases of vapor degreasing chemicals at the final use facility. The release sources are discussed in the order that they occur in the process (see [REF _Ref461778940 \h * MERGEFORMAT]). The most likely media of release (i.e., air, water, landfill, or incineration) are also identified. Table 4-1 presents the release sources, the likely media of release, and the models used to estimate the release. Air release due to evaporative losses from degreasing operation is expected to be the primary source of environmental release.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary of Environmental Releases and Likely Media of Release

Release	Description	Model	Standard EPA Model (✓)
1	Release to air from unloading of transport container	EPA/OAQPS AP-42 Loading Model	✓
2	Release to water, incineration, or land from cleaning of transport container.	EPA/OPPT Drum Residual Model	✓
3	Release to air from vapor degreaser machine	User-defined model (see Equation 4-2)	
4	Release to Water from Vapor Degreasing Wastewater	User-defined model (see Equation 4-3)	
5	Release to incineration from cleaning degreasing machine and disposing waste solvent disposal	User-defined model (see Equation 4-4)	

OPPT – Office of Pollution Prevention and Toxics.

All release equations below estimate daily release rates for a given site. To estimate annual releases for all sites for a given source, the daily release rates must be multiplied by the number of days of release and by the total number of sites using the vapor degreasing chemical (N_{sites}).

The entire volume of vapor degreasing chemical is expected to be either released to air (i.e., evaporative losses) or disposed/reclaimed in the spent solvent. Therefore, this document presents release estimation method for a 100 percent release scenario.

4.1 Control Technologies

Evaporative losses can be a significant source of air release and worker exposure during vapor degreasing operations. Equipment design changes, add-on controls, and work practices can be made to reduce air releases and associated occupational exposure.

The Halogenated Solvent Cleaning Machine NESHAP (40 CFR Part 63, Subpart T)[7] provides three general compliance strategies for owners or operators of batch vapor or in-line degreasing machines to meet the emission standard. One compliance option is to meet the control equipment standards, which includes as many as 10 combination of emission control equipment such as freeboard refrigeration devices, freeboard ratio, and working-mode covers. Some of these controls are described below (VADEQ, 2016; MN TAP, 2011; USEPA, 2004):

- ∞ **Covers** – Flat or rolling covers can be installed on the top of OTVDs to reduce air emissions. Automatic biparting covers that enclose the tank while the work load is being cleaned are also available.
- ∞ **Freeboard Refrigeration Device** – Installing refrigerated coils on the freeboard above the primary condenser coils can reduce air emissions from the degreasing tank.
- ∞ **Increased Freeboard Ratio** – The freeboard ratio is the height of the freeboard divided by the smallest interior freeboard width. Increasing the freeboard ratio reduces idling emissions.
- ∞ **Carbon Adsorption System** – Installing a solvent recovery device such as a carbon adsorption system can capture solvent in the exhaust and reduce emissions into the workplace.

[REF _Ref462155600 \h] is a summary of reported emission reduction for several add-on controls. As the table shows, air emissions from vapor degreasing machines can be reduced by up to 80 percent with properly maintained and operated control technology.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary of Reported Air Emission Reduction with Add-on Controls

Type of Control	Reduction in Air Emissions	Source
Adding covers	35 – 50%	(MN TAP, 2011)
Refrigerated freeboard coils	20 – 50% (above-freezing coils)	(VADEQ, 2016)

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[7] For additional information on the NESHAP, see [HYPERLINK "https://www.epa.gov/stationary-sources-air-pollution/halogenated-solvent-cleaning-national-emission-standards-hazardou-0"]

	30 – 80% (below-freezing coils)	
Carbon adsorption system	50%	(Kanegsberg and Kanegsberg, 2011a)

Note: The post-MACT solvent use rate presented in [REF _Ref480707602 \h * MERGEFORMAT] already accounts for the reduction in emissions and solvent usage from control technology. A control efficiency should not be applied if post-MACT data are used to estimate solvent use rate.

The European Chlorinated Solvent Association (ECSA) also provides classification of degreasing and surface cleaning machines based equipment configuration and level of control, ranging from Type I OTVD machines to Type V machines that are closed, non-vented, and operate under vacuum. Appendix C presents information on ECSA classifications (ECSA, 2013).

In addition to the control technologies discussed above, changes in work practices such as reducing room draft from general facility ventilation can also minimize air disturbances around the degreaser, which may reduce excessive diffusion of solvent vapors from the freeboard region.

4.2   Release to Air from Unloading of Transport Container (Release 1)

Vapor degreasing chemicals are supplied to the final use facilities as either neat solvent or as part of a solvent formulation. For nonvolatile chemicals (e.g., the vapor pressure is < 0.001 torr), releases to air are expected to be negligible during transfer.

If the vapor degreasing chemical is volatile, releases to air (Elocal$_{air}$) may occur from the displacement of saturated air when the chemical is transferred from the container to the vapor degreasing machine. The following EPA standard model (included in ChemSTEER) is recommended to estimate fugitive emission to air from unloading activities:

EPA/OAQPS AP-42 Loading Model – this model estimates air release from displacement of saturated vapor during transfer operations, assuming evaporation rate is negligible in comparison to the displacement rate.

The transfer operations model provides worst and typical case estimates for releases and exposures during transfer operations (e.g., transferring liquids from transport containers into storage tanks or mixers). [REF _Ref480447432 \h] lists the model inputs and default values. The models and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate air releases and exposures during transfer operations. Appendix B provides background information, model equations, and default values for several parameters the model uses to estimate daily releases to air.

Note the default model assumption of negligible evaporation may not be representative for highly volatile chemicals. Therefore, this model may not accurately estimate release for chemicals with vapor pressures above 35 mmHg. EPA does not otherwise have a standard method for estimating air release from transfer operations for highly volatile chemicals.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1].
EPA/OAQPS AP-42 Loading Model **Parameter Default Values for Air Releases During Unloading**

Input Parameter	Default Values
Saturation Factor	EPA defaults 0.5 (typical) and 1 (worst case) for all containers less than 5,000 gallons (USEPA, 2002b) (See Appendix B for alternative default saturation factors)
Frequency of Release	Equal to the lesser of $N_{container\_unload\_site\_yr}$ or $TIME_{operating\_days}$, See Sections 3.7.
Molecular Weight	Chemical-specific parameter (g/mol)
Number of Sites	Calculated in Section [REF _Ref62119037 \n \h]
Operating Hours for the Activity	Number of containers per site, per day (see Section [REF _Ref62119042 \n \h]) divided by the unload rate (USEPA, 2002b) (default unload rates are found in Appendix B)
Unloading Rate	EPA default 20 containers/hr for volumes between 20 and 1,000 gallons (USEPA, 1991) (Alternative default unload rates are found in Appendix B)
Container Volume	Default: 55-gallon drum (208 L) (consistent with Section [REF _Ref62119052 \n \h])
Vapor Pressure	Chemical-specific parameter (torr)
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions

4.3   **Release to Wastewater Treatment, Incineration, or Landfill from Cleaning of Transport Container (Release 2)**

Vapor degreasing chemicals can be supplied in a variety of container sizes, typically ranging from 1- to 55-gallon containers (Gallade Chemical, 2016; Tech Spray, 2016). The amount of vapor degreasing chemical remaining in transport containers will likely depend

on the size of the transport container. Therefore, the following standard EPA models may be used to estimate container residue releases:

EPA/OPPT Bulk Transport Residual Model may be used for large containers (e.g., totes, tank trucks, rail cars) containing greater than or equal to 100 gallons of liquid;

EPA/OPPT Drum Residual Model may be used for drums containing between 20 and 100 gallons of liquid;

EPA/OPPT Small Container Residual Model may be used for liquid containers containing less than 20 gallons; and

Note that these models estimate between 0.2 (bulk containers) and 3 percent (drums) of the received material may be released to the environment. The rationale, defaults, and limitations of these models are further explained in Appendix B. The release estimates are based on the current version of the models. Standard EPA/OPPT models are subject to change; therefore, the current version of the standard EPA/OPPT model should be used.

Where chemical-specific information is not available, vapor degreasing chemicals are assumed to be supplied in 55-gallon drums to maximize the fraction of container residue. The *EPA/OPPT Drum Residual Model* assumes liquids are pumped from drums and that up to 3% (a central tendency of 2.5%) of the liquid originally in the drums remains as residual after unloading. Alternative assumptions include 0.6% high-end and 0.3% central tendency when pouring liquids from drums.

If the number of containers used per site per year ($N_{container\_unload\_site\_yr}$) is fewer than the days of operation ($TIME_{operating\_days}$), the days of release equals the number of containers and the daily release is calculated based on the following equation:

$$Elocal_{container\_residue} = V_{container} \times \rho_{formulation} \times F_{chem} \times F_{container\_disp} \times 1\frac{container}{site-day} \quad (4\text{-}1a)$$

This release will occur over [$N_{container\_unload\_site\_yr}$] days/year from [$N_{sites}$] sites.

Where:

$Elocal_{container\_residue}$ = Daily release of chemical from container residue (kg chemical/site-day)

$V_{container}$ = Volume of transport container (Default: 208.1 L, equivalent to 55 gal)

$\rho_{formulation}$ = Density of chemical formulation (kg/L formulation; Default: 1 kg/L)

F_{chem} = Weight fraction of the chemical in formulation (Default: 1 kg chemical/kg formulation)

$F_{container\_disp}$ = Fraction of chemical remaining in the container as residue (Default: 0.03 kg container residue/kg formulation supplied in drums)

If the number of containers used per site per year ($N_{container\_unload\_site\_yr}$) is greater than the days of operation, the days of release equal the days of operation, and the average daily release is calculated based on Equation 4-1b. Note this may also be used if a container size is not assumed in Equation 4-1a and the number of containers used per site-year is unknown.

$$Elocal_{container\_residue} = Q_{chem\_site\_day} \times F_{container\_disp} \qquad (4\text{-}1b)$$

This release will occur over [$TIME_{operating\_days}$] days/year from [N_{sites}] sites.

Where:

$Elocal_{container\_residue}$ = Daily release of chemical from container residue (kg chemical/site-day)

$Q_{chem\_site\_day}$ = Daily use rate of vapor degreasing chemical (kg chemical/site-day)

$F_{container\_disp}$ = Fraction of chemical remaining in the container as residue (Default: 0.03 kg container residue/kg formulation supplied in drums)

There is no industry-specific information on container cleaning and waste disposal practices. Because vapor degreasing chemicals are solvents or component of solvent formulations, any residue is likely handled as hazardous wastes and disposed according to RCRA regulations (i.e., incineration). Environmental release and waste management information reported in the 2015 Toxics Release Inventory (TRI) suggests that less than one percent of on-site releases are discharged to water for common degreasing chemicals such as TCE, PERC, and methylene chloride. As such, it is unlikely that releases to water will occur directly at facilities performing vapor degreasing.

In some cases, however, empty containers could be sent to recyclers and reconditioners where they are cleaned and/or water-washed, resulting in trace amount of residue being routed to wastewater treatment. Wastewater treatment sludge may be subsequently

landfilled. As conservative, the default release from container cleaning should be assessed to water, incineration, or landfill.

4.4   Release to Air during Vapor Degreasing Operation (Release 3)

Evaporative emissions are expected to be the major source of release from vapor degreasing due to the high volatility of the solvents used and the design of the operation. Evaporative emissions vary based on the type of solvent used, the type of degreasing machine used, type and effectiveness of solvent recovery system (e.g., cooling coils), and other factors such as air drafts and parts loading / unloading (USEPA, 2006a; Mertens, 2010; USEPA, 2017). OTVD machines have the potential for higher evaporative emissions due to the larger vapor-air interface and losses from air drafts (Kanegsberg and Kanegsberg, 2011a). Enclosed degreasers, such as closed-loop degreasers and most conveyorized degreasers, have decreased evaporative emissions because the degreasing tank has limited contact with the outside atmosphere (Kanegsberg and Kanegsberg, 2011a). Airless or vacuum degreasers are expected to have minimal evaporative losses because they operate at a vacuum (Kanegsberg and Kanegsberg, 2011a).

[REF _Ref480286846 \h] summarizes the solvent loss fraction by machine type as obtained from the 2006 NESHAP document (USEPA, 2006a) and the 2017 NEI (USEPA, 2017). Loss fractions from the 2006 NESAHP document were calculated by dividing the estimated facility-level post-MACT solvent emissions by the post-MACT solvent use rate, and covers all evaporative emissions that occur at the degreasing facility. The 2017 NEI includes reported emission factors; however, only about 20% of facilities with reported degreasing operations provide emission factor estimates. In addition, some of the provided emission factor data were noted as potentially being not representative, were reported with inconsistent units (e.g., ton solvent emitted/gal solvent used, with unknown solvent use rate), and (in one case) no emission factor was provided because the solvent was consumed, which is not typical. Those emission factors were excluded from [REF _Ref480286846 \h].

It is important to note that the 2006 NESHAP document and the 2017 NEI do not account for the entire universe of vapor degreasers in the United States. In addition, these data are both facility and chemical-specific. Differing operating conditions and chemical vapor pressures affect the actual emissions during degreasing operations.

As shown in [REF _Ref480286846 \h], 81 percent of solvent used in an OTVD could be emitted to air on average. Similar levels of evaporative losses are observed for in-line degreasers; however, only two data points are available for this degreaser type. Evaporative losses for closed loop machines and web cleaners approach 100 percent; however, overall annual emissions for these machines are less than OTVDs because the solvent use rate is lower. Airless vacuum degreasers, on average, have much smaller solvent loss than the other machine types in [REF _Ref480286846 \h].

**Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary
of Solvent Loss Fraction by Machine Type**

Machine Type	Min	Max	Average	50th Percentile	95th Percentile	No. Data Points
Open-Top Vapor Degreaser (OTVD)	0.0084	1.0	**0.81** (default)	0.93	1.0	91
Closed Loop Vapor Degreaser [a]	0.98	1.0	0.99	0.99	1.0	2
Conveyorized Vapor Degreaser	0.0068	1.0	0.80	1.0	1.0	14
Web Cleaner	1.0	1.0	1.0	1.0	1.0	4
Airless Vacuum Degreaser	0.0015	0.032	0.0075	0.0015	0.026	6

Note: It is unclear whether the solvent use rate accounts for an initial solvent charge, or only reflects ongoing solvent replenishment. In some cases where the estimated solvent emission exceeded 100 percent, EPA assumed a solvent loss fraction of 1.0.

Sources: (USEPA, 2006a; USEPA, 2017)

[a] While solvent losses for closed loop degreasers approach 100 percent, actual solvent use rate is lower than other machine types.

If the type of degreasing machine is unknown, **81 percent evaporative loss** for OTVDs should be assumed because this is the default machine type (see Section [REF _Ref62116052 \n \h * MERGEFORMAT]). If pre-MACT data were previously used to calculate the solvent use rate, the control efficiency (see [REF _Ref462155600 \h]) can be applied if the specific type of control is known. Equation 4-2 calculates the quantity of the vapor degreasing chemical released to air.

$$\text{Elocal}_{evap} = Q_{chem\_site\_day} \times LF_{air} \times (1 - EF_{control}) \hspace{2cm} (4\text{-}2)$$

Where:

Elocal_{evap} = Daily release of chemical of interest to air due to evaporative losses (kg chemical released/site-day)

$Q_{chem\_site\_day}$ =   Daily use rate of chemical of interest (kg chemical/site-
day) (Default: see Section [REF _Ref62116101 \n \h])

LF_{air} =   Fraction of chemical evaporated to air (Default: 0.81 kg
chemical released / kg chemical used)

$EF_{Control}$ =   Engineering control efficiency (see [REF
_Ref462155600 \h] only if pre-MACT solvent use rate
data are used; default: 0 for OTVD with no control)

This release will occur over [$TIME_{operating\_days}$] days/year from each of [N_{sites}] sites. Where information on the specific equipment design and control technology is not known, an OTVD with no emission control should be assumed as default.

4.5   Release to Air from Equipment Cleaning

The release described in Section [REF _Ref480548249 \r \h] (Release 3) covers releases to air from all process activities related to the degreasing operation; therefore, this ESD does not separately assess air release from equipment cleaning for volatile chemicals (e.g., the vapor pressure is > 0.001 torr). Note the use of the *EPA/OPPT Penetration Model* (EPA default for indoor operations) to separately estimate air release from equipment cleaning will likely result in an overestimate, and that the total releases to all environmental media may be greater than the use rate for the chemical of interest.

4.6   Release to Water from Vapor Degreasing Wastewater (Release 5)

Wastewater releases from vapor degreasing may come from (Durkee, 2014; Kanegsberg and Kanegsberg, 2011a; NIOSH, 2002a, b, c, d):

- ∞ Moisture in the atmosphere that condenses into the degreasing solvent when exposed to condensation coils in OTVDs and conveyorized degreasers
- ∞ Water-based oils and lubricants on parts being degreased
- ∞ Steam used to regenerate carbon adsorbers used to control solvent emissions

These wastewaters may be contaminated with vapor degreasing chemicals, so they are sent to a gravity water separator, where water and vapor degreasing solvent are separated (NIOSH, 2002a, b, c, d). The wastewater from the water separator is then disposed of to a publicly owned treatment works (POTW) or directly to surface water (NIOSH, 2002a, b, c, d).

The operation of the water separator is such that the concentration of vapor degreasing chemicals in the wastewater leaving the separator is equal to the solubility of the vapor degreasing chemical in the water (Durkee, 2014). In cases where this concentration exceeds the limit set by the applicable national effluent guidelines, sites are likely to perform

some form of treatment for wastewater prior to discharge to ensure compliance with the effluent guideline prior to discharge.

The *EPA/OPPT Water Saturation Loss Model* may be used to estimate the quantity of vapor degreasing chemicals in the discharged wastewater. This model assumes that water contacted with the chemical becomes saturated with the chemical, consistent with (Durkee, 2014), and remains saturated at the time of disposal. To estimate the quantity of vapor degreasing chemical released in wastewater using the *EPA/OPPT Water Saturation Loss Model,* the volume of wastewater discharged from the water separator is needed. EPA (1977) estimated that less than one to two gallons of wastewater are collected in the water separator each day. However, this estimate does not account for wastewater generated from steam stripping of still bottoms in distillation units or from regeneration of carbon beds used for emission controls (where such controls are present). Because these data were not available, EPA (USEPA, 2020a) used an order of magnitude estimate to account for these releases. Based on the literature and the order of magnitude estimate, the default amount of wastewater is 2 to 20 gal/day (USEPA, 2020a).

The daily release to surface water or POTW is calculated based on the following equation:

$$\text{Elocal}_{\text{wastewater}} = WS_{\text{chem}} \times CF \times V_{\text{wastewater}} \times \frac{3.785\,L}{gal} \times \frac{kg}{1000\,grams} \quad (4\text{-}3)$$

Where:

$\text{Elocal}_{\text{wastewater}} =$ Daily release of chemical from wastewater (kg chemical/site-day)

$WS_{\text{chem}} =$ Water solubility of the vapor degreasing chemical of interest (g/L)

$CF =$ A factor to account for any variability, such as a known or estimated correction of the water solubility of the chemical or other corrections (unitless; Default: 1)

$V_{\text{wastewater}} =$ Daily volume of wastewater discharged (gal/day; Default: 2 to 20 gal/day)

4.7   Release to Incineration from Equipment Cleaning and Waste Solvent Disposal (Release 4)

The degreasing tank is cleaned periodically to replace dirty solvent. The frequency of equipment cleaning and solvent changeout will depend on the type of operation and the

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facility's volume throughput and could vary from once in several weeks to less than once per year. For example, a 1994 study estimates an 80-gallon degreasing tank with a 1.5 gallon per day oil loading rate being replaced every two to three weeks but noted that degreasers used for critical parts cleaning will be cleaned more frequently (Callahan, 1994). Another study estimates solvent changeout occurring four times per year (Morrison and Murphy, 2006).

Dirty solvent removed from the degreasing machine is usually recycled on-site or sent off-site for reclamation. For recycling and reclaim, distillation yields are on the order of 70 percent, with 30 percent sent off-site for use as cement kiln fuel (Callahan, 1994). Eventually, the vapor degreasing chemical will be either recycled, reused, or disposed as waste solvent. Sludge from the vapor degreaser, consisting of the vapor degreasing chemical, oil, tar, metal particles, buffing compounds, and other contaminants, will also be disposed as waste. Equation 4-3 calculates the quantity of the vapor degreasing chemical disposed in the spent solvent or waste sludge.

$$\text{Elocal}_{incin} = \frac{Q_{chem\_site\_yr} - \left(\left(\text{Elocal}_{air} + \text{Elocal}_{container\_residue}\right) \times N_{container\_unload\_site\_yr}\right) - \left(\left(\text{Elocal}_{evap} + \text{Elocal}_{wastewater}\right) \times \text{TIME}_{operating\_days}\right)}{FT_{changeout}}$$

(4-4)

Where:

$\text{Elocal}_{incin} =$	Daily release of chemical of interest to incineration (kg chemical released/site-day)
$Q_{chem\_site\_yr} =$	Annual use rate of chemical of interest (kg chemical/site-year) (Default: see Section [REF _Ref462578190 \r \h])
$\text{Elocal}_{air} =$	Daily release of chemical of interest to air from container unloading (kg chemical released/site-day)
$\text{Elocal}_{container\_residue}[8] =$	Daily release of chemical of interest as container residue (kg chemical released/site-day)
$N_{container\_unload\_site\_yr} =$	Number of transport containers unloaded at each site per year (containers/site-yr)
$\text{Elocal}_{evap} =$	Daily release of chemical of interest to air due to evaporative losses during degreaser operation (kg chemical released/site-day)
$\text{Elocal}_{wastewater} =$	Daily release of chemical from wastewater (kg chemical/site-day)

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[8] Calculated using either Equation 4-1a (if the number of containers per day is greater than or equal to 1) or Equation 4-1b (if the number of containers per day is less than 1).

$TIME_{operating\_days}$ = Number of operating days (days/yr) (Default: 296 days/yr, see Section [REF _Ref62116180 \n \h])

$FT_{changeout}$ = Frequency of solvent changeout (Default: 26 day/yr)

In lieu of chemical-specific data, EPA recommends assuming the solvent tank changeout occurs **once every two weeks, or 26 times per year.** This release will occur over $[FT_{changeout}]$ days/year from each of $[N_{sites}]$ sites.

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5.0   Occupational Exposure Assessments

As shown in [REF _Ref461778940 \h], workers may come into contact with the vapor degreasing chemical while unloading chemical from transport containers (i.e., charging the degreasing tank), during degreaser operation, and during cleaning and maintenance activities. This section presents methodologies for estimating occupational exposures during these activities. [REF _Ref216678759 \h] summarizes the source, physical state encountered, route, and model used to assess each exposure.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Summary of Occupational Exposures

Exposure	Description	Route of Exposure/Physical Form	Model	Standard EPA Model (✓)
A	All activities	Dermal exposure to liquid chemical.	*Dermal Exposure to Volatile Liquids Model*	✓
B	Unloading transport containers	Inhalation exposure to vapor emitted during unloading/filling.	*EPA/OPPT Mass Balance Model*	✓
C	Vapor degreaser operation	Inhalation exposure to vapor emitted from degreaser.	Personal breathing zone monitoring data reported in literature.	

Because vapor degreasing chemicals are volatile, inhalation exposure to vapor is expected to be the primary exposure route. While dermal exposure to the liquid form will also occur, the volatility of the chemical of interest and the time it takes to evaporate from the skin after dermal contact should be considered when assessing dermal exposure. The duration for dermal exposure for highly volatile chemicals may be short, but exposure may not be negligible if there is repeated dermal contact. Where available, industry-specific data are provided in this section.

5.1   Personal Protective Equipment

Worker exposure to vapor degreasing chemicals can be prevented by the use of engineering controls and best work practices. As a general rule of thumb, PPE is the least preferred method of controlling worker exposure.

A recent monitoring study of worker exposure at five vapor degreasing facilities across several industries indicated that respiratory protection was used at only one of five facilities studied. At this facility, one worker (out of 31) effectively used the respirator for less than 15 to 20 minutes for the entire work shift. Two other workers at the facility briefly wore air-purifying respirator but did not wear it properly and failed quantitative fit testing. Respirator was not used by other employees or in other facilities. The study also reported that only few workers occasionally wore gloves, and those who wore gloves did not choose the proper glove material for the vapor degreasing chemical (Hanley et al., 2010).

Based on these observations, worker exposure should be assessed assuming PPE is not worn in lieu of chemical-specific data.

5.2   Number of Workers Per Site

[REF _Ref462127154 \h] presents a list of North American Industry Classification System (NAICS) industry sectors that may have vapor degreasing operations. Because degreasing encompasses a large number of industry sectors, not all facilities in the identified NAICS code will perform surface cleaning via vapor degreasing (USEPA, 2016).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. List of Industry Sectors Likely to Perform Vapor Degreasing

NAICS Code	NAICS Description
314999	All Other Miscellaneous Textile Product Mills
321113	Sawmills
323111	Commercial Printing (except Screen and Books)
325180	Other Basic Inorganic Chemical Manufacturing
325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing

NAICS Code	NAICS Description
326299	All Other Rubber Product Manufacturing
331110	Iron and Steel Mills and Ferroalloy Manufacturing
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
331410	Nonferrous Metal (except Aluminum) Smelting and Refining
331420	Copper Rolling, Drawing, Extruding, and Alloying
332111	Iron and Steel Forging
332112	Nonferrous Forging
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)
332117	Powder Metallurgy Part Manufacturing
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing
332216	Saw Blade and Handtool Manufacturing
332311	Prefabricated Metal Building and Component Manufacturing
332313	Plate Work Manufacturing
332431	Metal Can Manufacturing
332510	Hardware Manufacturing
332618	Other Fabricated Wire Product Manufacturing
332721	Precision Turned Product Manufacturing
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing
332811	Metal Heat Treating
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring
332912	Fluid Power Valve and Hose Fitting Manufacturing
332913	Plumbing Fixture Fitting and Trim Manufacturing
332919	Other Metal Valve and Pipe Fitting Manufacturing
332994	Small Arms, Ordnance, and Ordnance Accessories Manufacturing
332996	Fabricated Pipe and Pipe Fitting Manufacturing

NAICS Code	NAICS Description
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing
333132	Oil and Gas Field Machinery and Equipment Manufacturing
333249	Other Industrial Machinery Manufacturing
333318	Other Commercial and Service Industry Machinery Manufacturing
333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333921	Elevator and Moving Stairway Manufacturing
333994	Industrial Process Furnace and Oven Manufacturing
333999	All Other Miscellaneous General Purpose Machinery Manufacturing
334220	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing
334413	Semiconductor and Related Device Manufacturing
334416	Capacitor, Resistor, Coil, Transformer, and Other Inductor Manufacturing
334417	Electronic Connector Manufacturing
334419	Other Electronic Component Manufacturing
334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
335120	Lighting Fixture Manufacturing
335121	Residential Electric Lighting Fixture Manufacturing
335210	Small Electrical Appliance Manufacturing
335312	Motor and Generator Manufacturing
335313	Switchgear and Switchboard Apparatus Manufacturing
335911	Storage Battery Manufacturing
335921	Fiber Optic Cable Manufacturing
335929	Other Communication and Energy Wire Manufacturing
335999	All Other Miscellaneous Electrical Equipment and Component Manufacturing
336320	Motor Vehicle Electrical and Electronic Equipment Manufacturing

NAICS Code	NAICS Description
336340	Motor Vehicle Brake System Manufacturing
336411	Aircraft Manufacturing
336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing
336414	Guided Missile and Space Vehicle Manufacturing
336510	Railroad Rolling Stock Manufacturing
337125	Household Furniture (except Wood and Metal) Manufacturing
337127	Institutional Furniture Manufacturing
339114	Dental Equipment and Supplies Manufacturing
339990	All Other Miscellaneous Manufacturing
339992	Musical Instrument Manufacturing
339995	Burial Casket Manufacturing
339999	All Other Miscellaneous Manufacturing
488111	Air Traffic Control
493110	General Warehousing and Storage
811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance

Source: (U.S. Census Bureau, 2014)

The Bureau of Labor Statistics' (BLS') Occupational Employment Statistics (OES) provide employment data for workers in specific industries and occupations. The industries are classified by NAICS codes (identified previously), and occupations are classified by Standard Occupational Classification (SOC) codes. [REF _Ref462127499 \h] identifies the occupations among the affected NAICS codes where the employee may come into contact with the vapor degreasing chemical. Workers may be exposed via the dermal and inhalation routes through direct contact with the vapor degreasing chemical. Other employees (occupational non-users) present at the facility who work in the vicinity of vapor degreasing operation may also be exposed via inhalation of vapor or through incidental contact.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. SOC Codes with Potential Exposure to Vapor Degreasing Chemicals

SOC	Occupation	Type of Exposure
17-2000	Engineers	Occupational non-user
17-3000	Drafters, Engineering Technicians, and Mapping Technicians	Occupational non-user
19-4000	Life, Physical, and Social Science Technicians	Occupational non-user
49-1000	Supervisors of Installation, Maintenance, and Repair Workers	Occupational non-user
49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	Worker
49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	Worker
49-9010	Control and Valve Installers and Repairers	Worker
49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	Worker
49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	Worker
49-9060	Precision Instrument and Equipment Repairers	Worker
49-9070	Maintenance and Repair Workers, General	Worker
49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	Worker
51-1000	Supervisors of Production Workers	Occupational non-user
51-2000	Assemblers and Fabricators	Worker
51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	Worker

Source: (Bureau of Labor Statistics, 2016)

[REF _Ref462128363 \h] presents the number of potentially exposed workers and occupational non-users for the NAICS and SOC combinations identified previously. The data show a total of 112,701 facilities with an average of 34 employees per facility. It should be noted that not all 112,701 facilities will perform vapor degreasing operations. In addition, not all employees at the facility will be potentially exposed to the vapor degreasing chemical, which is why the total number of employees with potential exposure is less than the total number of

employees for the affected NAICS. On average, **approximately 9 workers and 4 occupational non-users per facility** (13 total people potentially exposed should be assumed in assessments that do not differentiate between workers and ONUs) are potentially exposed to the vapor degreasing chemical in the industry sectors of interest. See Appendix D for additional details in the methods used to estimate number of potentially exposed workers and occupational non-users.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Number of Potentially Exposed Employees within Vapor Degreasing Industry Sectors

Total Employment in Affected NAICS			Employees with Potential Exposure [a]			
Facilities	Number of Employees	Employees per Facility	Total Workers	Total Occupational Non-Users	Workers Exposed per Facility	Occupational Non-Users Exposed per Facility
112,701	3,826,254	34	1,036,797	468,989	9 (rounded)	4 (rounded)

Source: (Bureau of Labor Statistics, 2016; U.S. Census Bureau, 2015)

a – Number of workers and occupational non-users associated with the relevant SOC codes under the NAICS industry sectors for vapor degreasing.

Note: NAICS codes are available at the 6-digit level. However, some of the BLS employment data are only available at the 4-digit or 5-digit NAICS level. In this case, the employment estimates were refined using total employment data in the U.S. Census' Statistics of U.S. Businesses (SUSB) by adjusting for granularity. This adjustment is done by calculating the employment in specific 6-digit NAICS of interest as a percentage of employment in the BLS 5-digit NAICS.

5.3 Dermal Exposure Duration

Dermal exposure to liquid is expected for workers involved in vapor degreasing operations. Workers may come into contact with the degreasing chemical while unloading the chemical from transport containers into the degreasing tank, or while changing out spent solvent or performing maintenance and cleaning activities. Based on the design of the operation, vapor degreasing chemicals are expected to be volatile, with many chemicals having vapor pressure above 35 mmHg at room temperature (i.e., highly volatile). See [REF _Ref425510835 \h] for vapor pressures of several common vapor degreasing chemicals.

Highly volatile chemicals may evaporate rapidly from the hand upon dermal contact. As such, the duration of dermal exposure may not exceed the duration of the activity (USEPA, 1991). [REF _Ref462758081 \h] below provides the estimated evaporation time for several common vapor degreasing chemicals. The evaporation time is calculated using the volatilization model at a typical skin surface temperature of 32°C (Frasch et al., 2014). As shown in the table, a thin layer of semi and highly volatile chemicals will evaporate from the hand within several minutes.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Estimated Evaporation Time after Dermal Contact for Select Vapor Degreasing Chemicals

Chemical	Molecular Weight (g/mol)	Vapor Pressure, 32°C (mmHg)	Temperature (K)	Vapor Generation Rate, G (g/s)	Skin Loading (mg/cm^2)	2-Hand Surface Area (cm^2)	Evaporation Time (min)
1-BP	123	184	305	0.111	2.1	1,070	0.34
TCE	131	96	305	0.061	2.1	1,070	0.61
PERC	166	27	305	0.020	2.1	1,070	1.84
MC	85	569	305	0.257	2.1	1,070	0.15
Acetone	58	307	305	0.104	2.1	1,070	0.36
Cyclohexane	84	133	305	0.060	2.1	1,070	0.63

Source for molecular weight and vapor pressure: (NIST, 2016)

Estimation of Evaporation Time after Dermal Contact

The estimated evaporation time in [REF _Ref462758081 \h * MERGEFORMAT] is calculated using the following EPA volatilization model (USEPA, 1991):

$$G = \frac{8.24\text{E-}8 \times MW^{0.835} \times X \times VP \times (1/29 + 1/MW)^{0.25} \times vz^{0.5} \times A}{T^{0.05} \times d^{0.5} \times P^{0.5}}$$

G = Vapor generation rate (g/s)
MW = Molecular weight (g/mol)
X = Vapor pressure correction factor (EPA/OPPT default: 1; dimensionless)
VP = Vapor pressure (mmHg)
vz = Air velocity (assumed as 59.05 ft/min or 0.3 m/s; (Frasch et al., 2014))
A = Area (cm²; calculated based on diameter of pool opening)
T = Temperature (assumed as 305K, or 32°C for typical skin surface)
d = Diameter of pool opening (assumed as 16 cm, approximate length of hand)
A = Area of liquid pool (cm²; assumed to approximate a circle)
P = Pressure (EPA/OPPT Default: 1 atm)

The Dermal Exposure to Volatile Liquids Model assumes a skin loading of 2.1 mg/cm2 per exposure event and a surface area of 1,070 cm2 for two hands. Using default values provided by the model, the evaporation time can be calculated as follow:

Despite the short exposure duration, it is not conservative to assume the dermal exposure is negligible, because actual exposure will depend on whether the chemical is rapidly absorbed through the skin and whether the exposed surface area is replenished through repeated contacts. For example, the workers may come into dermal contact with a specified amount of vapor degreasing chemical after unloading a drum containing the chemical into the solvent tank. Even though the chemical on the hands will quickly evaporate, the worker may be exposed repeatedly if he or she unloads additional drums throughout the day.

As such, this ESD recommends that users follow the EPA *Dermal Exposure to Volatile Liquids Model* to calculate exposure dose. This model calculates exposure dose based on the amount of chemical adhering to the skin that evaporates and absorbs in the skin after a contact event, assuming one contact event per day.

5.4   Dermal Exposure to for All Activities (Exposure A)

Workers may be exposed to the vapor degreasing chemical via the dermal route while draining, cleaning, and performing maintenance on the solvent tank. Workers have been reported to reach into the solvent bath area while fixing broken machine parts (CSAC, 2016), which could lead to substantial dermal exposure.

To assess dermal exposure to volatile liquids during these activities, the *Dermal Exposure to Volatile Liquids Model* can be used. The model estimates potential worker exposure using the following equation:

$$\text{EXP}_{\text{dermal}} = \frac{Q_{\text{liquid\_skin}} \times f_{abs}}{PF} \times \text{AREA}_{\text{surface}} \times N_{\text{exp\_incident}} \times F_{\text{chem}} \quad (5\text{-}1)$$

Where:

$\text{EXP}_{\text{dermal}} =$ Potential dermal exposure to the chemical of interest per day (mg chemical/day)

$Q_{\text{liquid\_skin}} =$ Quantity of liquid degreasing formulation remaining on skin (Defaults: 2.1 mg component/cm^2-incident (USEPA, 2000))

$f_{\text{abs}} =$ Fraction of applied mass that is absorbed by the skin (Use Equation 5-2 or select a default from [REF _Ref62112404 \h * MERGEFORMAT])

$PF =$ Protection factor of gloves, if used (Default: 1 [no gloves used])

$\text{AREA}_{\text{surface}} =$ Surface area of contact (Default: 1,070 cm^2 for 2 hands (USEPA, 2000))

$N_{\text{exp\_incident}} =$ Number of exposure incidents per day (Default: 1 incident/day)

$F_{\text{chem}} =$ Mass fraction of the chemical of interest (Default: 1 mg chemical/mg formulation) (See Section [REF _Ref62048323 \n \h * MERGEFORMAT])

To estimate f$_{\text{abs}}$, the *Dermal Exposure to Volatile Liquids Model* uses the following equation for large doses of applied chemical:

$$f_{\text{abs}} = \frac{1}{X+1} \quad\quad\quad (5\text{-}2)$$

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Where:

f_{abs} = Fraction of applied mass that is absorbed by the skin (Dimensionless)

X = Ratio of the liquid evaporative flux to the steady-state dermal absorption flux (Dimensionless; see Equation 5-3)

To estimate X, the *Dermal Exposure to Volatile Liquids Model* uses the following equation:

$$X = 3.4 \times 10^{-3} \times u^{0.78} \times \frac{VP \times MW^{3.4}}{k_{oct}^{0.76} \times S_w} \qquad (5\text{-}3)$$

Where:

X = Ratio of the liquid evaporative flux to the steady-state dermal absorption flux (Dimensionless)

u = Air velocity (m/s; Default: 0.1674 m/s [industrial setting] or 0.0878 m/s [commercial setting; default for unknown setting] (Baldwin and Maynard, 1998))

VP = Vapor pressure (torr; chemical-specific parameter)

MW = Molecular weight (g/mol; chemical-specific parameter)

K_{oct} = Octanol:water partition coefficient (Dimensionless; chemical-specific parameter)

S_w = Water solubility ($\mu g/cm^3$; chemical-specific parameter)

If chemical-specific parameters needed for Equation 5-3 are unknown, select f_{abs} from [REF _Ref62112404 \h] for the chemical that most nearly resembles the molecular weight and vapor pressure of the chemical of interest. If the chemical of interest is unlike any of the chemicals in [REF _Ref62112404 \h], a **default f_{abs} of 1 should be used**.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Fraction Absorbed (f_{abs}) for Common Degreasers

Chemical	MW (g/mol)	VP at 20°C (mmHg or torr)	Fraction Absorbed (f_{abs})
Methylene chloride	85	435	0.08 (industrial setting) 0.13 (commercial setting)
Carbon tetrachloride	154	115	0.04 (industrial setting) 0.07 (commercial setting)
1-bromopropane (1-BP)	123	111	0.08 (industrial setting) 0.12 (commercial setting)

Chemical	MW (g/mol)	VP at 20°C (mmHg or torr)	Fraction Absorbed (f_{abs})
Trichloroethylene (TCE)	131	74	0.08 (industrial setting) 0.13 (commercial setting)
1, 4-Dioxane	88	40	0.78 (industrial setting) 0.86 (commercial setting)
Tetrachloroethylene (PERC)	166	18.5	0.13 (industrial setting) 0.19 (commercial setting)
N-Methylpyrrolidone	99	0.345	1 (industrial setting) 1 (commercial setting)
		Default	*1*

Source: (USEPA, 2020a-g)

5.5 Inhalation Exposure to Vapor from Unloading of Transport Containers (Exposure B)

The method used to calculate inhalation exposure ($EXP_{inhalation}$) depends on the volatility and the physical state of the chemical of interest. [SEQ CHAPTER \h \r 1]Inhalation exposure to vapor is assumed negligible for nonvolatile chemicals of interest (e.g., the partial pressure of the chemical of interest in the formulation is < 0.001 torr).

For volatile chemicals, workers may be exposed to vapor emitted during unloading of chemicals from transport containers into the solvent tank. For this activity, the *EPA/OAQPS AP-42 Loading Model* can be used to estimate vapor generation from the displacement of saturated vapor during transfer and filling activities. This model calculates vapor generation using the chemical's physical-chemical properties and assume that the rate of evaporation during unloading is negligible compared to the rate of displacement.

The vapor generation rate can then be used with the *EPA/OPPT Mass Balance Inhalation Model* to estimate the amount of chemical inhaled by the worker during unloading activities. The model and all current EPA defaults have been programmed into ChemSTEER; EPA recommends using this software to calculate inhalation exposure to volatile chemicals during transfer operations. Appendix B explains the background and derivation of the model and provides EPA default values for several model parameters.

[REF _Ref480455565 \h] lists the model inputs and default values. Note that the exposure hours per day is equivalent to the operating hours per day for this activity (consistent with Section 4.2 calculations), but EPA assumes an exposure duration of eight hours per day

for a given worker if the actual exposure duration or work shift duration is not known. Similarly, EPA assumes that the number of exposure days per year is the same as the number of days of transfer, although EPA often assumes 250 exposure days per year if the number of days of transfer significantly exceeds 250 days per year. These exposure duration maximum defaults are based on full-time employment and considers an individual worker's vacation, sick, and weekend time (i.e., a 40-hour work week over 50 weeks per year).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1].
***EPA/OPPT Mass Balance Model* Parameter Default Values During Transfers**

Input Parameter	Default Values
Inhalation Rate	Default = 1.25 m^3/hr (USEPA, 1991)
Exposure Days	Consistent with the Frequency of Release determined in Section 4.2, up to 250 days per year
Vapor Generation Rate	Calculated by the *EPA/OAQPS AP-42 Loading Model* (Section 4.2)
Exposure Duration	Consistent with the Operating Hours determined in Section 4.2, up to 8 hours per day
Mixing Factor	EPA defaults 0.5 (typical) and 0.1 (worst case) (USEPA, 1991)
Molecular Weight	Chemical-specific parameter
Number of Sites	Calculated in Section [REF _Ref62119129 \n \h]
Ventilation Rate	EPA defaults 3,000 ft^3/min (typical) and 500 ft^3/min (worst case) for indoor conditions (default for containers less than 1,000 gallons (USEPA, 1991) (See Appendix B for alternative default ventilation rates)
Vapor Pressure	Chemical-specific parameter
Vapor Pressure Correction Factor	Standard EPA default = 1

Note: The model also assumes standard temperature and pressure along with ideal gas interactions.

5.6   Inhalation Exposure to Vapor during Degreasing Operation
       (Exposure C)

Employees may be exposed via inhalation of vapor emitted from the degreasing machine while performing degreasing tasks, or while performing other work activities in proximity of the machine. EPA has developed modeling approaches for estimating worker exposures during vapor degreasing operations, which involve Monte Carlo simulation and are utilized in EPA's Risk Evaluations for existing chemicals (USEPA, 2020a-g). However, the use of applicable monitoring data is preferable to modeling; therefore, this exposure estimate utilizes available monitoring data. [REF _Ref462566318 \h] below summarizes available full-shift personal breathing zone monitoring data for several vapor degreasing chemicals since 1990. The data were collected from multiple sources and facilities. Most studies involved exposure monitoring at facilities that operated one or more batch vapor degreasers (typically OTVD); some studies did not report the specific type of degreaser present.

The data in [REF _Ref462566318 \h] cover employees who directly operate the vapor degreaser (workers). The data in [REF _Ref62046902 \h] cover employees who perform work near the degreasing area (occupational non-users). None of the exposure level measured exceeded the applicable OSHA Permissible Exposure Limit (PEL) for the chemical being monitored. However, exposure to TCA was found to approach 200 ppm in some cases.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary of Worker Personal Breathing Zone Concentrations for Vapor Degreasing reported in Literature since 1990

| Chemical | MW (g/mol) | VP at 20°C (mmHg) | Full-shift TWA (ppm) | | | | | Data Points | OSHA PEL |
			Min	Max	Average	Central tendency (50th %-tile)	High-end (95th %-tile)		
1,1,1-trichloroethane (TCA)	133	100	1.92	198	112	110	191	22	350 ppm TWA
1-bromopropane (1-BP)	123	111	0.03	152	14.7	6.70	49.3	155	None
1, 4-Dioxane	88	40	2.00	13.3	4.00	3.30	6.46	20	100 ppm TWA

Tetrachloroethylene (PERC)	166	18.5	0.01	37.8	6.59	1.00	31.5	91	100 ppm TWA
Trichloroethylene (TCE)	131	74	ND	85.6	17.7	12.3	57.3	145	100 ppm TWA
All Data			ND	198	18.4	5.90	78.1	433	
All Data Excluding TCA			ND	152	13.5	**5.00** (central tendency)	**46.0** (high-end)	411	

MW – Molecular weight.
ND – Non-detected.
VP – Vapor pressure.
OSHA PEL – OSHA Permissible Exposure Limit at time of study.
Sources: (DOEHRS - IH, 2018; DOW Deutschland, 2014; Miller, 2019; NIOSH, 1973, 1975, 1976, 1978, 1980, 1981, 1982, 1984, 1988, 1989a, 1989b, 1991, 2001, 2002a, 2002b, 2002c; OSHA, 2013; OSHA, 2019; Pantucharoensri et al., 2004; U.S. EPA, 2006a)

**Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary
of ONU Exposure Concentrations for Vapor Degreasing reported
in Literature since 1990**

| Chemical | MW (g/mol) | VP at 20°C (mmHg) | Full-shift TWA (ppm) | | | | | Data Points | OSHA PEL |
			Min	Max	Average	Central tendency (50th %-tile)	High-end (95th %-tile)		
1-bromopropane (1-BP)	123	111	0.01	2.40	0.17	0.10	0.46	75	None
Tetrachloroethylene (PERC)	166	18.5	0.04	7.10	1.26	0.55	4.89	14	100 ppm TWA
Trichloroethylene (TCE)	131	74	ND	10.9	2.35	1.11	9.09	10	100 ppm TWA
All Data			ND	10.9	0.54	**0.54** (central tendency)	**2.22** (high-end)	99	

MW – Molecular weight.
ND – Non-detected.
VP – Vapor pressure.
OSHA PEL – OSHA Permissible Exposure Limit at time of study.
Sources: (DOEHRS - IH, 2018; DOW Deutschland, 2014; Miller, 2019; NIOSH, 1973, 1975, 1976, 1978, 1980, 1981, 1982, 1984, 1988, 1989a, 1989b, 1991, 2001, 2002a, 2002b, 2002c; OSHA, 2013; OSHA, 2019; Pantucharoensri et al., 2004; U.S. EPA, 2006a)

While actual measured breathing zone concentrations may be impacted by several factors, including the number and type of vapor degreasing machines, presence of engineering control, and duration of vapor degreasing operation, chemicals with higher volatility evaporate more readily into the workplace air, generally resulting in higher worker breathing zone concentrations. EPA recommends the user compares the molecular weight and vapor pressure for the chemical of interest to the available surrogate data in [REF _Ref462566318 \h] and [REF _Ref62046902 \h] to determine the appropriate worker and occupational non-user exposure level. In lieu of chemical-specific data, EPA recommends assessing an **exposure concentration of 5.00 ppm (central tendency) to 46.0 ppm (high-end) for workers** and **0.54 ppm (central tendency) to 2.22 ppm (high-end) for occupational non-users** based on all available data reported in literature. The data excludes TCA, because TCA is no longer used in vapor degreasing. Data prior to 1990 are excluded from the summary as dated exposure information may not be representative of present-day exposure levels. EPA recommends assuming workers are exposed for the entire duration of the work shift, **or 8 hours per day.**

5.7   Inhalation Exposure to Vapor from Equipment Cleaning

The exposure described in Section [REF _Ref479684669 \r \h] (Exposure C) covers potential inhalation exposure from all degreasing-related activities; therefore, this ESD does not separately assess inhalation exposure to vapor for workers during equipment cleaning.

6.0   Sample Calculations

This section presents an example of how the equations described in Sections 3 through 5 may be used to estimate releases of and exposures to a chemical used in vapor degreasing. The default values used in these calculations are presented in Sections 3, 4, and 5 and should be used only in the absence of site-specific information. Sample calculations are based on the following assumptions:

1. Vapor degreasing chemical production volume (Q_{chem_yr}) is *50,000 kg chemical/yr*.
2. The chemical is a liquid and is received at final use site neat, or 100 percent by weight (F_{chem} = 1.0).
3. The end use occurs at 25 sites.
4. The chemical has a molecular weight of 120 g/mol, a vapor pressure of 45 torr at room temperature, and a water solubility of 1.3 g/L.

6.1   General Facility Estimates

6.1.1   *Type of Degreasing Machine*

The type of degreasing machine is unknown, so an OTVD is assumed.

6.1.2   *Days of Operation (TIME$_{operating\_days}$)*

If specific information is not available to estimate the days of operation ($TIME_{operating\_days}$), a default value of 296 days per year for OTVDs should be assumed.

6.1.3   *Concentration of Vapor Degreasing Chemical (F_{chem})*

The concentration of the vapor degreasing chemical is given as F_{chem} = 1.

6.1.4   *Annual Use Rate of Vapor Degreasing Chemical (Qchem_site_yr)*

Since the annual use rate of vapor degreasing chemical is unknown, a default value for $Q_{chem\_site\_yr}$ of 2,083 kg/site-yr for batch systems, post-MACT should be assumed.

6.1.5   *Daily Use Rate of Vapor Degreasing Chemical ($Q_{chem\_site\_day}$)*

The daily use rate of a vapor degreasing can be calculated using Equation 3-1.

$$Q_{chem\_site\_day} = \frac{Q_{chem\_site\_yr}}{TIME_{working\_days}}$$

$$Q_{chem\_site\_day} = \frac{2{,}083 \text{ kg/site-yr}}{296 \text{ day/yr}} = 7.04 \frac{\text{kg}}{\text{site-day}}$$

Where:

$Q_{chem\_site\_day}$ = Daily use rate of vapor degreasing chemical (kg/site-day)

$Q_{chem\_site\_yr}$ = Annual use rate of vapor degreasing chemical (Default: 2,083 kg/site-yr for batch systems, post-MACT)

$TIME_{operating\_day}$ = Number of operating days (Default: 296 days/yr)

6.1.6   *Number of Sites (N_{sites})*

The number of final use facilities using the chemical of interest (N_{sites}) can be estimated using Equation 3-2:

$$N_{sites} = \frac{Q_{chem\_yr}}{Q_{chem\_site\_day} \times TIME_{operating\_days}}$$

$$N_{sites} = \frac{50{,}000 \text{ kg/yr}}{7.04 \text{ kg/site-day} \times 296 \text{ day/yr}} = 23.99 \text{ sites} = 24 \text{ sites}$$

Where:

N_{sites} = Number of sites using the precursor chemical (sites)

Q_{chem_yr} = Annual production volume of chemical of interest (kg chemical/yr)

$Q_{chem\_site\_day}$ = Daily use rate of vapor degreasing chemical (kg chemical/site-day)

$\text{TIME}_{\text{working\_days}}=$ Number of operating days at semiconductor manufacturing sites (days/yr) (Default: 296 days/yr)

The estimated number of sites using default values for an OTVD is 24 sites. For the remaining sample calculations, the assumption of 24 sites is used.

6.1.7 *Number of Transport Containers Unloaded per Site ($N_{container\_unload\_site\_yr}$)*

The number of transport containers unloaded annually per site can be estimated based on the daily use rate, container size, and the purity of the chemical:

$$N_{container\_\text{unload\_site\_yr}} = \frac{Q_{\text{chem\_site\_day}} \times \text{TIME}_{\text{operating\_days}}}{F_{\text{chem}} \times V_{\text{container}} \times \rho_{formulation}}$$

$$N_{container\_\text{unload\_site\_yr}} = 7.04 \frac{\text{kg}}{\text{site-day}} \times \frac{296 \text{ day}}{\text{yr}} \times \frac{1 \text{ kg formulation}}{1 \text{ kg chemical}} \times \frac{\text{container}}{208 \text{ L}}$$
$$\times \frac{L}{1 \text{ kg formulation}}$$

$$= 10.02 \; (rounded \; to \; 10) \frac{container}{site - yr}$$

Where:

$N_{\text{container\_unload\_site\_yr}}$ = Number of transport containers unloaded at each site per year (containers/site-yr)

$Q_{\text{chem\_site\_day}}$ = Daily use rate of vapor degreasing chemical (kg/site-day)

F_{chem} = Weight fraction of chemical in the formulation as received (Default: 1 kg chemical/kg formulation)

$\text{TIME}_{\text{operating\_days}}$ = Number of operating days (days/yr) (Default: 296 days/yr)

$V_{\text{container}}$ = Volume of transport container (Default: 208 L container)

$\rho_{\text{formulation}}$ = Density of chemical formulation (Default: 1kg/L)

6.2   Environmental Releases

6.2.1   *Release to Air from Unloading of Transport Container (Release 1)*

Since the chemical of interest is volatile, it will be emitted during transfer due to the displacement of saturated air. The *EPA/OAQPS AP-42 Loading Model* may be used to estimate the average vapor generation rate ($Q_{vapor\_generation}$), which is then used to estimate the daily release to air of the chemical of interest ($Elocal_{air}$). [REF _Ref426293776 \h * MERGEFORMAT] summarizes the model's inputs.

[Eqn. B-5]

$$Q_{vapor\_generation} = \frac{F_{saturation\_factor} \times MW_{c\square em} \times \left(V_{containeer} \times \frac{3785.4\ cm^3}{gal} \right) \times \left(\frac{RATE_{fill}}{3600\ sec/\square our} \right) \times F_{correction\_factor} \times \left(\frac{VP_{c\square em}}{760\ torr/atm} \right)}{R \times TEMP_{ambient}}$$

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]. Summary of ChemSTEER Inputs for Release 1

Input Parameter	Variable	Units	ChemSTEER Input
Molecular Weight	$MW_{chem.}$	g/mol	120
Saturation Factor	$F_{saturation\_factor}$	Dimensionless	Typical = 0.5 Worst Case = 1
Vapor Pressure	$VP_{chem.}$	Torr	45
Container Volume	$V_{container}$	Gal	55
Fill Rate	$RATE_{fill}$	containers/hour	20
Temperature	$TEMP_{ambient}$	K	298
Vapor Correction Factor	$F_{correction\_factor}$	Dimensionless	1
Gas Constant	R	$Atm \cdot cm^3 / K \cdot mol$	82.05

Therefore:

$$Q_{vapor\_generation} = 1.7 \times 10^{-1} \text{ g/s } (typical\ case)$$

$$Q_{vapor\_generation} = 3.4 \times 10^{-1} \text{ g/s } (worst\ case)$$

Using $Q_{vapor\_generation}$ calculated in Equation B-5 and the other standard default values presented in [REF _Ref480447432 \h] for container unloading, the model then estimates the daily release to air using the following equation:

$$\text{Elocal}_{air} = Q_{vapor\_generation} \times \text{TIME}_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \qquad [\text{Eqn. B-7}]$$

$$\text{Elocal}_{air} = \left(1.7 \times 10^{-1} \text{ to } 3.4 \times 10^{-1}\right) \text{ g/s} \times \left(\frac{10 \text{ containers/site-yr}}{10 \text{ days/yr} \times 20 \text{ containers/hr}}\right)$$
$$\times \frac{3600 \text{ sec/hr}}{1000 \text{ g/kg}}$$

$$\text{Elocal}_{air} = 3.0 \times 10^{-2} \text{ to } 6.1 \times 10^{-2} \text{ kg chem. emitted/site-day}$$

...over 10 days/year (one day per container) from 24 sites.

6.2.2 *Release to Wastewater Treatment, Incineration, or Landfill from Cleaning of Transport Container (Release 2)*

Since the number of containers used per site per year ($N_{container\_unload\_site\_yr}$, Equation 3-3) is fewer than the days of operation ($TIME_{operating\_days}$), the days of release equals the number of containers and the daily release is calculated based on the following equation:

$$Elocal_{container\_residue} = V_{container} \times \rho_{formulation} \times F_{chem} \times F_{container\_disp} \times 1 \frac{container}{site - day}$$

$$Elocal_{container\_residue} = \frac{208 \text{ L formulation}}{container} \times \frac{1 \text{ kg}}{L} \times 1.0 \times \frac{0.03 \text{ kg disposed}}{\text{kg formulation}} \times \frac{1 \text{ container}}{\text{site-day}}$$

$$Elocal_{container\_residue} = 6.24 \frac{\text{kg chemical disposed}}{\text{site-day}}$$

The release will occur over 10 day/yr from 24 sites to wastewater treatment, incineration, or landfill.

6.2.3 *Release to Air from Vapor Degreasing Operation (Release 3)*

The amount of vapor degreasing chemical released as a result of evaporative losses can be calculated using Equation 4-3:

$$Elocal_{evap} = Q_{chem\_site\_day} \times LF_{air} \times (1 - EF_{control})$$

$$Elocal_{evap} = 7.04 \text{ kg/site-day} \times 0.81 \times 1 = 5.70 \text{ kg/site-day}$$

Where:

$Elocal_{evap} =$ Daily release of chemical of interest to air from evaporative losses (kg chemical released/site-day)

$Q_{chem\_site\_day} =$ Daily use rate of chemical of interest (kg chemical/site-day)

$LF_{air} =$ Fraction of chemical evaporated to air (Default: 0.81 kg chemical released / kg chemical used)

$EF_{Control} =$ Engineering control efficiency (Default: 0 for OTVD with no control)

This release will occur over 296 days/year from each of 24 sites to air.

6.2.4 *Release to Air from Equipment Cleaning*

Release 3 covers releases to air from all process activities related to the degreasing operation; therefore, this ESD does not separately assess air release from equipment cleaning for volatile chemicals.

6.2.5 *Release to Water from Vapor Degreasing Wastewater (Release 5)*

The amount of vapor degreasing chemical released to water from vapor degreasing wastewater (surface water or POTW) can be calculated using Equation 4-3:

$$Elocal_{wastewater} = WS_{chem} \times CF \times V_{wastewater} \times \frac{3.785\ L}{gal} \times \frac{kg}{1000\ grams}$$

$$Elocal_{wastewater} = 1.3\frac{grams}{L} \times 1 \times 2\ to\ 20\frac{gal}{day} \times \frac{3.785\ L}{gal} \times \frac{kg}{1000\ grams}$$

$$Elocal_{wastewater} = 0.0098\ to\ 0.098\ kg/site\text{-}day$$

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Where:

$Elocal_{wastewater}$ =   Daily release of chemical from wastewater (kg chemical/site-day)

WS_{chem} =   Water solubility of the vapor degreasing chemical of interest (g/L)

CF =   A factor to account for any variability, such as a known or estimated correction of the water solubility of the chemical or other corrections (unitless; Default: 1)

$V_{wastewater}$ =   Daily volume of wastewater discharged (gal/day; Default: 2 to 20 gal/day)

This release will occur over 296 days/year from each of 24 sites to water (surface water or POTW).

6.2.6   *Release to Incineration from Equipment Cleaning and Waste Solvent Disposal (Release 4)*

The amount of vapor degreasing chemical released from equipment cleaning and solvent changeout can be calculated using Equation 4-4. Based on chemical-specific use rate of 2,000 kilograms per site-year (50,000 kg/yr and 25 sites):

$$Elocal_{incin} = \frac{Q_{chem\_site\_yr} - \left(\left(Elocal_{air} + Elocal_{container\_residue}\right) \times N_{container\_unload\_site\_yr}\right) - \left(\left(Elocal_{evap} + Elocal_{wastewater}\right) \times TIME_{operating\_days}\right)}{FT_{changeout}}$$

$$Elocal_{incin} = \frac{2{,}000 \text{ kg site/yr} - \left((0.061 + 6.24) \times 10 \text{ day/yr}\right) - \left((5.70 + 0.098) \times 296 \text{ day/yr}\right)}{26 \text{ day/yr}}$$

$Elocal_{incin}$ = 8.49 kg/site-day

Where:

$Elocal_{incin} =$ Daily release of chemical of interest to incineration (kg chemical released/site-day)

$Q_{chem\_site\_yr} =$ Annual use rate of chemical of interest (kg chemical/site-year) (Default: see Section [REF _Ref462578190 \r \h])

$Elocal_{air} =$ Daily release of chemical of interest to air from container unloading (kg chemical released/site-day)

$Elocal_{container\_residue} =$ Daily release of chemical of interest as container residue (kg chemical released/site-day)

$N_{container\_unload\_site\_yr} =$ Number of transport containers unloaded at each site per year (containers/site-yr)

$Elocal_{evap} =$ Daily release of chemical of interest to air due to evaporative losses during degreaser operation (kg chemical released/site-day)

$Elocal_{wastewater} =$ Daily release of chemical from wastewater (kg chemical/site-day)

$TIME_{operating} =$ Number of operating days per year (Default: 296 day/yr)

$FT_{changeout} =$ Frequency of solvent changeout (Default: 26 day/yr)

This release will occur over 26 days/year from each of 24 sites to incineration.

6.3 Occupational Exposures

6.3.1 *Number of Workers*

Per Section [REF _Ref62118695 \n \h], there are a total of 13 people potentially exposed per site (9 workers/site and 4 ONUs/site).

6.3.2 *Duration of Dermal Contact*

Highly volatile chemicals (vapor pressure > 35 torr) may evaporate quickly from the skin, thereby reducing the duration of dermal exposure. If the chemical of interest is highly volatile, the EPA volatilization model can be used to estimate the vapor generation rate (USEPA, 1991):

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$$G = \frac{8.24E\text{-}8 \times MW^{0.835} \times X \times VP \times (1/29 + 1/MW)^{0.25} \times vz^{0.5} \times A}{T^{0.05} \times d^{0.5} \times P^{0.5}}$$

$$G = \frac{8.24E\text{-}8 \times 120^{0.835} \times 1 \times 45 \times (1/29 + 1/120)^{0.25} \times 59^{0.5} \times 201}{305^{0.05} \times 16^{0.5} \times 1^{0.5}}$$

$$G = 0.027 \text{ g/s}$$

Where:

G	= Vapor generation rate (g/s)
MW	= Molecular weight (g/mol)
X	= Vapor pressure correction factor (EPA/OPPT default: 1; dimensionless)
VP	= Vapor pressure (mmHg)
vz	= Air velocity (assumed as 59.05 ft/min or 0.3 m/s; (Frasch et al., 2014))
T	= Temperature (assumed as 305K, or 32°C for typical skin surface)
d	= Diameter of pool opening (assumed as 16 cm, approximate length of hand)
A	= Area of liquid pool (cm^2; assumed to approximate a circle with diameter d)
P	= Pressure (EPA/OPPT Default: 1 atm)

The *Dermal Exposure to Volatile Liquids Model* assumes a skin loading of 2.1 mg/cm2 per exposure event and a surface area of 1,070 cm2 for two hands. Using default values provided by the model, the evaporation time can be calculated as follow:

$$\text{Evaporation time (min)} = \frac{2.1 \text{ mg/cm}^2 \times 1,070 \text{ cm}^2}{G \times 1,000 \text{ mg/g} \times 60 \text{ s/min}}$$

Evaporation time = 1.40 minutes

6.3.3   *Dermal Exposure to Liquid from All Activities (Exposure A)*

The potential for dermal exposure during unloading of transport containers can be calculated using the *Dermal Exposure to Volatile Liquids Model*, using the default fraction absorbed fabs = 1 from Table 5-6 and default protection factor PF = 1:

$$EXP_{dermal} = \frac{Q_{liquid\_skin} \times f_{abs}}{PF} \times AREA_{surface} \times N_{exp\_incident} \times F_{chem}$$

$$= \frac{\frac{2.1\ mg}{cm^2 - incident} \times 1}{1} \times 1{,}070\ cm^2 \times \frac{1\ incident}{day} \times 1$$

$$EXP_{dermal} = 2{,}247\ mg/day$$

…for 9 workers/site (ONU dermal exposure is not expected) over 250 days/year

Where:

EXP_{dermal} =	Potential dermal exposure to the chemical of interest per day (mg chemical/day)
Q_{liquid_skin} =	Quantity of liquid degreasing formulation remaining on skin (Defaults: 2.1 mg component/cm^2-incident (USEPA, 2000))
f_{abs} =	Fraction of applied mass that is absorbed by the skin (1 per [REF _Ref62112404 \h * MERGEFORMAT])
PF =	Protection factor of gloves, if used (Default: 1 [no gloves used])
$AREA_{surface}$ =	Surface area of contact (Default: 1,070 cm^2 for 2 hands (USEPA, 2000))
$N_{exp\_incident}$ =	Number of exposure incidents per day (Default: 1 incident/day)

6.3.4   *Inhalation Exposure to Vapor from Unloading of Transport Containers (Exposure B)*

Inhalation exposure to vapor during container unloading can be calculated using the *EPA/OPPT Mass Balance Inhalation Model* (with vapor generation rate from the *EPA/OAQPS AP-42 Loading Model*):

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$$C_v = \text{lesser of } 170,000 \times T \times G / (MW \times Q \times k) \text{ or}$$

$$1,000,000 \times X \times VP / 760$$

$$C_v = 47.3 \text{ to } 2,838 \text{ ppm}$$

$$C_m = C_v \times MW / V_m = (47.3 \text{ to } 2,838 \text{ ppm}) \times (120 \text{ g/mol}) / (24.45 \text{ L/mol})$$

$$C_m = 232.1 \text{ to } 13,928 \text{ mg/m}^3$$

$$I = C_m \times b \times h = (232.1 \text{ to } 13,928 \text{ mg/m}^3) \times 1.25 \text{ m}^3/\text{hr} \times 0.0018 \text{ hr/day}$$

$$I = 0.0536 \text{ to } 32.2 \text{ mg/day}$$

......for 9 workers/site (ONU exposure during this activity is not quantified) over 250 days/year

6.3.5   *Inhalation Exposure to Vapor during Degreasing Operation (Exposure C)*

Based on the default values recommended in Section [REF _Ref479684669 \r \h] and [REF _Ref462566318 \h], the exposure concentration is 5.0 (central tendency) to 46 (high-end) ppm for workers. Therefore:

$$C_m = C_v \times MW / V_m = (5.0 \text{ to } 46 \text{ ppm}) \times (120 \text{ g/mol}) / (24.45 \text{ L/mol})$$

$$C_m = 24.5 \text{ to } 226 \text{ mg/m}^3$$

$$I = C_m \times b \times h = (24.5 \text{ to } 226 \text{ mg/m}^3) \times 1.25 \text{ m}^3/\text{hr} \times 8 \text{ hr/day}$$

$$I = 245 \text{ to } 2,260 \text{ mg/day}$$

...for 9 workers/site over 250 days/year

Based on the default values recommended in Section [REF _Ref479684669 \r \h] and [REF _Ref462566318 \h], the exposure concentration is 0.54 (central tendency) to 2.22 (high-end) ppm for ONUs. Therefore:

$$C_m = C_v \times MW / V_m = (0.54 \text{ to } 2.22 \text{ ppm}) \times (120 \text{ g/mol}) / (24.45 \text{ L/mol})$$

$$C_m = 2.65 \text{ to } 10.9 \text{ mg/m}^3$$

$$I = Cm \times b \times h = (2.65 \text{ to } 10.9 \text{ mg/m}^3) \times 1.25 \text{ m}^3/\text{hr} \times 8 \text{ hr/day}$$

$$I = 26.5 \text{ to } 109 \text{ mg/day}$$

…for 4 ONUs/site over 250 days/year

6.3.6 *Inhalation Exposure to Vapor from Equipment Cleaning*

Exposure C covers potential inhalation exposure from all degreasing-related activities; therefore, this ESD does not separately assess inhalation exposure to vapor for workers during equipment cleaning.

7.0   Data Gaps/Uncertainties and Future Work

EPA wishes to make this ESD as detailed and up-to-date as possible, such that the risk-screening assessments reflect current industrial practices. EPA is most interested in obtaining information about the vapor degreasing industry that can be used to assess a generic site performing vapor degreasing.

This ESD relies heavily on data obtained from the 2011 NEI, and the 2006 EPA Risk Assessment for the halogenated solvent cleaning source category, NIOSH health hazard evaluations, and journal articles. Reviewers should feel free to provide additional information and data that could further enhance and improve the methods described in this ESD, as well as to recommend additional resources that may be useful to the development of this ESD.

The key data gaps are summarized below. Note that the data gaps are listed in order of importance (the first being most important):

1. It is unclear whether the post-MACT solvent consumption data in the 2006 Risk Assessment includes an initial solvent charge (i.e., filling the degreasing tank when purchasing and using a new solvent), or whether the data only reflects ongoing solvent replenish rate. If the data does not include the initial charge, the use of such data to calculate loss fraction to air may be overly conservative.

2. EPA believes container residue is likely handled as a hazardous waste; however, TRI data suggests that some releases to water for vapor degreasing chemicals do occur. In addition, there is some uncertainty on container handling and cleaning practices. Additional information on how containers are typically handled in the industry and the potential release media will be helpful in determining the release media associated with this activity.

3. EPA does not currently have a standard method for quantifying dermal exposure to highly volatile chemicals. While such exposure can be quantified by calculating the dermal absorption dose (i.e., mass of chemical absorbed through the skin), EPA expects that users of this document will not have all parameters needed for such a calculation, such as the permeability coefficient for the chemical of interest. Additional information, data, or methods on quantifying such exposure will be useful in enhancing the dermal exposure assessment approach presented in this ESD.

4. EPA does not currently have industry-specific information on container selection and container handling procedures. It is unclear whether the

container type or handling practices will differ depending on the volatility of the chemicals in order to minimize evaporative losses.

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APPENDIX A: ESTIMATION EQUATION SUMMARY AND DEFAULT PARAMETER VALUES

Table A-1 summarizes the equations introduced in Sections 3, 4, and 5 of this document. These equations may be used in evaluating releases of and exposures to vapor degreasing chemicals. A description of each input variable and associated default is provided in Table A-2.

Table A-1. Vapor Degreasing Chemical Release and Exposure Calculation Summary

General Facility Estimates	
Daily Use Rate per Site of Vapor Degreasing Chemical (Q_{chem_site_day})	
$$Q_{chem\_site\_day} = \frac{Q_{chem\_site\_yr}}{TIME_{operating\_days}}$$	(Eqn. 3-1)
Number of Sites (N_{sites})	
$$N_{sites} = \frac{Q_{chem\_yr}}{Q_{chem\_site\_day} \times TIME_{operating\_days}}$$	(Eqn. 3-2)
Number of Containers Unloaded per Site (N_{container_unload_site_yr})	
$$N_{container\_unload\_site\_yr} = \frac{Q_{chem\_site\_day} \times TIME_{operating\_days}}{F_{chem} \times V_{container} \times \rho_{formulation} \times 3.785 \frac{L}{gal}}$$	(Eqn. 3-3)

Table A-2. Environmental Release Calculation Summary

Source	Possible Medium	Daily Release Rates (kg/site-day), Elocal (for Given Sources)
Transfer Operations (Release 1)	Air	EPA/OAQPS AP-42 Loading Model (See Section 4.2)
Container Residue (Release 2)	Water Land Incineration	If $N_{container\_unload\_site\_yr}$ is less than $TIME_{operating\_days}$: $$Elocal_{container\_residue} = V_{container} \times \rho_{formulation} \times F_{chem} \times F_{container\_disp} \times 1 \frac{container}{site - day}$$ (Eqn. 4-1a) This release will occur over $N_{container\_unload\_site\_yr}$ day/year from [N_{sites}] sites. If $N_{container\_unload\_site\_yr}$ is greater than $TIME_{operating\_days}$: $$Elocal_{container\_residue} = Q_{chem\_site\_day} \times F_{container\_disp}$$ (Eqn. 4-1b) This release will occur over [$TIME_{operating\_days}$] days/year from [N_{sites}] sites.
Vapor Degreasing Operation (Release 3)	Air	$$Elocal_{evap} = Q_{chem\_site\_day} \times LF_{air} \times (1 - EF_{control})$$ (Eqn. 4-2) This release will occur over [$TIME_{operating\_days}$] days from [N_{sites}] sites.
Vapor Degreasing Wastewater (Release 4)	Water	$$Elocal_{wastewater} = WS_{chem} \times CF \times V_{wastewater} \times \frac{3.785\,L}{gal} \times \frac{kg}{1000\,grams}$$ (Eqn. 4-3) This release will occur over [$TIME_{operating\_days}$] days from [N_{sites}] sites.
Equipment Cleaning and Waste Solvent Disposal (Release 4)	Incineration	$$Elocal_{incin} = \frac{Q_{chem\_site\_yr} - \left((Elocal_{air} + Elocal_{container\_residue}) \times N_{container\_unload\_site\_yr} \right) - \left((Elocal_{evap} + Elocal_{wastewater}) \times TIME_{operating\_days} \right)}{FT_{changeout}}$$ (Eqn. 4-4) This release will occur over [$FT_{changeout}$] days from [N_{sites}] sites.

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Table A-3. Occupational Exposure Calculation Summary

Occupational Exposure Calculations
Number of Workers Exposed Per Site: As an estimate, EPA recommends assuming 9 workers and 4 occupational non-users per site for all sites, absent site-specific information.
Dermal Exposures during All Activities (Exposure A): Dermal Exposure to Volatile Liquids Model (See Section [REF _Ref62119333 \n \h])
Inhalation Exposure to Vapor from Unloading of Transport Containers (Exposure B): EPA/OPPT Mass Balance Inhalation Model (See Section [REF _Ref62119181 \n \h])
Inhalation Exposure to Vapor during Degreasing Operation (Exposure C): User-defined model (see Section [REF _Ref479684669 \n \h])

Table A-4. Parameter Declaration and Documentation Summary

Variable	Variable Description	Default Value	Data Source
$AREA_{surface}$	Surface area of contact (cm^2)	1,070 (2 hands)	(USEPA, 2013)
$Elocal_{air}$	Daily release of vapor degreasing chemical to air from transfer operations (kg chemical/site-day)	Calculated	Section [REF _Ref62119380 \n \h]

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Variable	Variable Description	Default Value	Data Source
Elocal$_{\text{container\_residue}}$	Daily release of vapor degreasing chemical from container residue (kg chemical/site-day)	Calculated	Section [REF _Ref62119384 \n \h]
Elocal$_{\text{evap}}$	Daily release of vapor degreasing chemical to air due to evaporative losses (kg/site-day)	Calculated	Section [REF _Ref62119391 \n \h]
Elocal$_{\text{wastewater}}$	Daily release of wastewater from vapor degreasing machines (kg/site-day)	Calculated	Section [REF _Ref62119433 \n \h]
Elocal$_{\text{incin}}$	Daily release of vapor degreasing chemical from equipment cleaning and solvent changeout (kg/site-day)	Calculated	Section [REF _Ref62457131 \n \h]
EF$_{\text{control}}$	Engineering control efficiency	0	Section [REF _Ref62119440 \n \h]
EXP$_{\text{inhalation}}$	Inhalation exposure to the chemical of interest per day (mg chemical/day)	Calculated	Sections [REF _Ref62119448 \n \h], [REF _Ref479684669 \n \h], [REF _Ref62119454 \n \h]
EXP$_{\text{dermal}}$	Potential dermal exposure to the chemical of interest per day (mg chemical/day)	Calculated	Sections [REF _Ref62119458 \n \h]
F$_{\text{chem}}$	Mass fraction of the chemical of interest in the vapor degreasing formulation (kg chemical/kg formulation).	1	Section [REF _Ref62119469 \n \h]
F$_{\text{container\_disp}}$	Fraction of vapor degreasing formulation remaining in the container as residue	0.03	(USEPA, 2002a)
FT$_{\text{changeout}}$	Frequency of equipment cleaning and solvent changeout (day/yr)	26	Section [REF _Ref62457131 \n \h]

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Variable	Variable Description	Default Value	Data Source
LF_{air}	Fraction of vapor degreasing chemical evaporated to air	0.81	Section [REF _Ref62119490 \n \h]
$N_{container\_unload\_site\_yr}$	Number of transport containers unloaded at each site per year (containers/site-yr)	Calculated	Section [REF _Ref62119495 \n \h]
$N_{exp\_incident}$	Number of exposure incidents per day (incident/day)	1	(USEPA, 2000)
N_{sites}	Number of sites using the chemical of interest (sites).	Calculated	Section [REF _Ref62119499 \n \h]
Q_{chem_yr}	Annual use rate for the chemical of interest (kg chemical/yr)	Calculated	Section [REF _Ref62119525 \n \h]
$Q_{chem\_site\_yr}$	Annual use rate for the chemical of interest per site (kg chemical/site-yr)	Calculated	Section [REF _Ref62119515 \n \h]
$Q_{chem\_site\_day}$	Daily use rate for the chemical of interest per site (kg chemical/site-day)	Calculated	Section [REF _Ref62119536 \n \h]
Q_{liquid_skin}	Quantity of liquid component remaining on skin (mg/cm^2-incident)	2.1	(USEPA, 2000)
$RATE_{container\_unloading}$	Container unloading rate (containers/hr)	20 containers/hr (drums)	(USEPA, 1991)
$RATE_{breathing}$	Typical worker breathing rate (m^3/hr)	1.25	(USEPA, 1991)
$\rho_{formulation}$	Density of the vapor degreasing formulation (kg/L)	1	EPA assumption
$TIME_{exposure}$	Duration of exposure (hr/day)	8	Appendix B
$TIME_{operating\_days}$	Number of operating days at facilities that perform vapor degreasing operations (day/yr)	296	Section [REF _Ref62119543 \n \h]

Variable	Variable Description	Default Value	Data Source
$TIME_{unloading\_hours}$	Number of hours unloading containers per day (hr/day)	8	(USEPA, 1991)
$V_{container}$	Volume of transport container (L/container)	208	Section [REF _Ref62119552 \n \h]

APPENDIX B: BACKGROUND INFORMATION AND EQUATIONS/DEFAULTS FOR THE
STANDARD EPA ENVIRONMENTAL RELEASE AND WORKER EXPOSURE MODELS

B.1. INTRODUCTION

This appendix provides background information and a discussion of the equations, variables, and default assumptions for each of the standard release and exposure models used by EPA in estimating environmental releases and worker exposures. The models described in this appendix are organized into the following three sections:

∞ Section B.2: Chemical Vapor Releases & Associated Inhalation Exposures;

∞ Section B.3: Container Residue Release Models (non-air); and

∞ Section B.4: Dermal Exposure Models.

Please refer to the guidance provided in the ESD for estimating environmental releases and worker exposures using these standard models, as it may suggest the use of certain overriding default assumptions to be used in place of those described for each model within this appendix.

This appendix includes a list of the key reference documents that provide the background and rationale for each of the models discussed. These references may be viewed in their entirety through the ChemSTEER Help System. To download and install the latest version of the ChemSTEER software and Help System, please visit the following EPA web site:

[HYPERLINK "https://www.epa.gov/tsca-screening-tools/chemsteer-chemical-screening-tool-exposures-and-environmental-releases"]

B.2. CHEMICAL VAPOR RELEASES & ASSOCIATED INHALATION EXPOSURES

This section discusses the models used by EPA to estimate chemical vapor generation rates and the resulting volatile releases to air and worker inhalation exposures to that chemical vapor. The volatile air release models (discussed in B.2.1) calculate both a vapor generation rate ($Q_{vapor\_generation}$; g/sec) and the resulting daily release rate of the chemical vapors to air. The *EPA/OPPT Mass Balance Inhalation Model* (discussed in Section B.2.2) uses the value of $Q_{vapor\_generation}$, calculated by the appropriate release model, to estimate the resulting inhalation exposure to that released vapor.

B.2.1 Vapor Generation Rate and Volatile Air Release Models

The following models utilize a series of equations and default values to calculate a chemical vapor generation rate ($Q_{vapor\_generation}$; g/sec) and the resulting daily volatile air release rate ($Elocal_{air}$; kg/site-day):

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∞ *EPA/OPPT Penetration Model* – evaporative releases from an exposed liquid surface located indoors;

∞ *EPA/OPPT Mass Transfer Coefficient Model* – evaporative releases from an exposed liquid surface located outdoors; and

∞ *EPA/OAQPS AP-42 Loading Model* – releases of volatile chemical contained in air that is displaced from a container being filled.

Each of these models is described in greater detail in the following sections:

B.2.1.1   EPA/OPPT Penetration Model

Model Description and Rationale:

The *EPA/OPPT Penetration Model* estimates releases to air from evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining volatile releases from activities that are performed *indoors*[1] or when air velocities are expected to be *less than or equal to 100 feet per minute*.

A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this model and the *Mass Transfer Coefficient Model* against experimentally measured evaporation rates described laminar airflow conditions existing up to 100 feet per minute. The paper compared the *Penetration Model* to experimental evaporation rate data measured under laminar (less than 100 feet per minute) and turbulent (above 100 feet per minute) airflow conditions. While the *Penetration Model* did not provide accurate estimates of evaporation rates under turbulent air flow conditions (relative to the *Mass Transfer Coefficient Model*), the results modeled under laminar flow conditions were found to more closely approximate the experimental data (usually within 20 percent). It is assumed that the conditions of an indoor work area most closely approximate laminar airflow conditions.

The model was originally developed using Fick's second law of diffusion. Model results were tested against experimental results of a study on evaporation rates for 15 compounds studied at different air velocities and temperatures in a test chamber. The experimental data confirmed the utility and accuracy of the model equation. Sample activities in which the *Penetration Model* may be used to estimate volatile releases to air are sampling liquids and cleaning liquid residuals from smaller transport containers (e.g., drums, bottles, pails).

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[1] Similar air releases from surfaces located at *outdoor* locations (air speeds > 100 ft/min) are calculated using the *Mass Transfer Coefficient Model* (see the description provided in this section of Appendix B).

Model Equations:

The model first calculates the average vapor generation rate of the chemical from the exposed liquid surface using the following equation:

[B-1]

$$Q_{vapor\_generation}$$
$$= \frac{(8.24 \times 10^{-8}) \times MW_{chem}^{0.835} \times F_{correction\_factor} \times VP_{chem} \times \left(\frac{1}{29} + \frac{1}{MW_{chem}}\right)^{0.25} \times RATE_{air\_speed}^{0.5} \times AREA_{opening}}{TEMP_{ambient}^{0.05} \times D_{opening}^{0.5} \times P_{ambient}^{0.5}}$$

Where:

$Q_{vapor\_generation}$ = Average vapor generation rate (g of chemical/sec)

MW_{chem} = Molecular weight of the chemical of interest (g/mol)

$F_{correction\_factor}$ = Vapor pressure correction factor (EPA default =1)[1]

VP_{chem} = Vapor pressure of the chemical of interest (torr)

$RATE_{air\_speed}$ = Air speed (EPA default = 100 feet/min; value must be $\leq$ 100 feet/min for this model)

$AREA_{opening}$ = Surface area of the static pool or opening (cm^2; B × $D_{opening}^2$ / 4)

$TEMP_{ambient}$ = Ambient temperature (EPA default = 298 K)

$D_{opening}$ = Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)

$P_{ambient}$ = Ambient pressure (EPA default = 1 atm)

Note: The factor 8.24×10^{-8} in Equation B-1 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapor generation rate ($Q_{vapor\_generation}$) calculated in Equation B-1, the model then estimates the daily release to air for the activity using the following equation:

$$Elocal_{air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \qquad [B-2]$$

Where:

$Elocal_{air}$ = Daily release of the chemical vapor to air from the activity (kg/site-day)

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[1]The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{correction\_factor}$ × VP_{chem}). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

$Q_{vapor\_generation}$ = Average vapor generation rate (g of chemical/sec; see Equation B-1)

$TIME_{activity\_hours}$= Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

References:

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces.* U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment,* Volume 1 (Equation 4-24 and Appendix K). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.2 EPA/OPPT Mass Transfer Coefficient Model

Model Description and Rationale:

The *EPA/OPPT Mass Transfer Model* estimates releases to air from the evaporation of a chemical from an open, exposed liquid surface. This model is appropriate for determining this type of volatile release from activities that are performed *outdoors*[1] or when air velocities are expected to be *greater than 100 feet per minute.* A draft paper (Arnold and Engel, 1999) evaluating the relative performance of this and the *Penetration Model* against experimentally measured evaporation rates, described laminar airflow conditions existing up to 100 feet per minute. It is assumed that the conditions of an indoor process area most closely approximate laminar air flow conditions, while outdoor conditions approximate turbulent airflow conditions above 100 feet per minute.

As discussed in the draft paper, the model is predicated on the solution of the classical mass transfer coefficient model with the gas-phase mass transfer coefficient estimated by the correlation of Mackay and Matsugu. Results were tested against experimental results on 19 compounds generated by four different experimenters over a wide range of experimental conditions. While the *Mass Transfer Coefficient Model* matched the data well (usually within 20 percent), it was found that the *Penetration Model* (see description in previous section) outperformed the *Mass Transfer Coefficient Model* under laminar flow (i.e., "indoor") conditions. Therefore, the *Penetration Model* is used as a default for estimating indoor evaporation rates, while the *Mass Transfer Coefficient Model* is used for outdoor rates. Sample activities in which the *Mass Transfer Coefficient Model* may be used to estimate volatile

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[1]Similar air releases from surfaces located at *indoor* locations (air speeds $\leq$ 100 ft/min) are calculated using the *Penetration Model* (see the description provided in this section of Appendix B).

releases to air are cleaning liquid residuals from process equipment and bulk transport containers (e.g., tank trucks, rail cars).

Model Equations:

The model first calculates the average vapor generation rate of the chemical from the shallow pool using the following equation:

[B-3]

$$Q_{vapor\_generation} = \frac{(1.93 \times 10^{-7}) \times MW_{chem}{}^{0.78} \times F_{correction\_factor} \times VP_{chem} \times \left(\frac{1}{29} + \frac{1}{MW_{chem}}\right)^{0.33} \times RATE_{air\_speed}{}^{0.78} \times AREA_{opening}}{TEMP_{ambient}{}^{0.4} \times D_{opening}{}^{0.11} \times \left(TEMP_{ambient}{}^{0.5} - 5.87\right)^{2/3}}$$

Where:

$Q_{vapor\_generation}$ = Average vapor generation rate (g of chemical of interest/sec)
MW_{chem} = Molecular weight of the chemical of interest (g/mol)
$F_{correction\_factor}$ = Vapor pressure correction factor (EPA default =1)[1]
VP_{chem} = Vapor pressure of the chemical of interest (torr)
$RATE_{air\_speed}$ = Air speed (EPA default = 440 feet/min; value must be > 100 feet/min for this model)
$AREA_{opening}$ = Surface area of the static pool or opening (cm²; B × $D_{opening}{}^2$ / 4)
$TEMP_{ambient}$ = Ambient temperature (EPA default = 298 K)
$D_{opening}$ = Diameter of the static pool or opening (cm; See Table B-1 for appropriate EPA default values)

Note: The factor 1.93×10^{-7} in Equation B-3 accounts for various unit conversions. See Arnold and Engel, 1999, for the derivation of this constant.

Using the vapor generation rate ($Q_{vapor\_generation}$) calculated in Equation B-3, the model then estimates the daily release to air for the activity using the following equation:

$$Elocal_{air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \qquad [B-4]$$

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[1] The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material × VP_{chem}), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

Where:

> Elocal$_{air}$ =   Daily release of the chemical vapor to air from the activity (kg/site-day)
>
> Q$_{vapor\_generation}$ =   Average vapor generation rate (g of chemical/sec; see Equation B-3)
>
> TIME$_{activity\_hours}$ =   Operating hours for the release activity per day (hours/site-day; See Table B-1 for appropriate EPA default values)

References:

Arnold, F.C. and Engel, A.J. Pre-publication draft article entitled, *Evaporation of Pure Liquids from Open Surfaces*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. October 1999.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

B.2.1.3   EPA/OAQPS AP-42 Loading Model

Model Description and Rationale:

The EPA's Office of Air Quality Planning and Standards (OAQPS) *AP-42 Loading Model* estimates releases to air from the displacement of air containing chemical vapor as a container/vessel is filled with a liquid. This model assumes that the rate of evaporation is negligible compared to the vapor loss from the displacement.

This model is used as the default for estimating volatile air releases during both loading activities and unloading activities. This model is used for unloading activities because it is assumed while one vessel is being unloaded another is assumed to be loaded. The *EPA/OAQPS AP-42 Loading Model* is used because it provides a more conservative estimate than either the *EPA/OPPT Penetration Model* or the *Mass Transfer Coefficient Model* for unloading activities.

Model Equations:

The model first calculates the average vapor generation rate of the chemical from the displacement during loading/filling operation using the following equation:

[B-5]

[EMBED Equation.3]Where:

$Q_{vapor\_generation}$ =   Average vapor generation rate (g of chemical/sec)

$F_{saturation\_factor}$ =   Saturation factor (See Table B-1 for appropriate EPA default values)

MW_{chem} =   Molecular weight of the chemical of interest (g/mol)

V_{cont_empty} =   Volume of the container (gallons; see Table B-1 for appropriate EPA default values)

$RATE_{fill}$ =   Fill rate (containers/hour; see Table B-1 for appropriate EPA default values)

$F_{correction\_factor}$ =   Vapor pressure correction factor (EPA default =1)[1]

VP_{chem} =   Vapor pressure of the chemical of interest (torr)

R =   Universal Gas Constant (82.05 atm-cm^3/mol-K)

$TEMP_{ambient}$ =   Ambient temperature (EPA default = 298 K)

       Using the vapor generation rate ($Q_{vapor\_generation}$) calculated in Equation B-5, the model then estimates the daily release to air for the activity using the following equation:

$$Elocal_{air} = Q_{vapor\_generation} \times TIME_{activity\_hours} \times \frac{3600 \text{ sec/hour}}{1000 \text{ g/kg}} \qquad [B-6]$$

Where:

$Elocal_{air}$ =   Daily release of the chemical vapor to air from the activity (kg/site-day)

$Q_{vapor\_generation}$ =   Average vapor generation rate (g of chemical/sec; see Equation B-5)

$TIME_{activity\_hours}$ =   Operating hours for the release activity per day (hours/site-day; see Table B-1 for appropriate EPA default values)

Reference:

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

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[1]The default vapor pressure correction factor, $F_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = $F_{correction\_factor} \times VP_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material $\times VP_{chem}$), thus the $F_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

Table B-1. Standard EPA Default Values Used in Vapor Generation Rate/Volatile Air Release Models

Activity Type (Location)	V_{cont_empty} (gallons)	$D_{opening}$ (cm)	$RATE_{fill}$ (containers/hour)	$F_{saturation\_factor}$	
Container-Related Activities (e.g., filling, unloading, cleaning, open surface/evaporative losses):					
Bottles (Indoors)	1 (Range: <5)	5.08 (<5,000 gals)	60	Typical: 0.5 Worst Case: 1	Number of
Small Containers (Indoors)	5 (Range: 5 to <20)				
Drums (Indoors)	55 (Range: 20 to <100)		20		
Totes (Indoors)	550 (Range: 100 to <1,000)				
Tank Trucks (Outdoors)	5,000 (Range: 1,000 to <10,000)	7.6 ($\geq$5,000 gals)	2	1	
Rail Car (Outdoors)	20,000 (Range: 10,000 and up)		1		
Equipment Cleaning Activities:					
Multiple Vessels (Outdoors)	Not applicable	92	Not applicable	1	
Single, Large Vessel (Outdoors)					
Single, Small Vessel (Outdoors)					
Sampling Activities:					

Activity Type (Location)	V_{cont_empty} (gallons)	$D_{opening}$ (cm)	$RATE_{fill}$ (containers/hour)	$F_{saturation\_factor}$	
Sampling Liquids (Indoors)	Not applicable	Typical: 2.5[a] Worst Case: 10	Not applicable	1	
Other Activities:					
Continuous Operation	If other scenario-specific activities are identified that use one of the vapor generation rate/air release models described in this section, the ESD will describe the model and provide appropriate default values for the model parameters.			1	
Batch Operation					(Hour

a - The "typical" diameter default value of 2.5 cm was adopted as a policy decision
in 2002, which supersedes the previous default value of 7 cm shown in the 1991
U.S. EPA reference document.

B.2.2   Chemical Vapor Inhalation Model

The following sections describe the EPA standard model for estimating worker inhalation exposures to a chemical vapor, utilizing a vapor generation rate ($Q_{vapor\_generation}$).

B.2.2.1   EPA/OPPT Mass Balance Model

Model Description and Rationale:

The *EPA/OPPT Mass Balance Model* estimates a worker inhalation exposure to an estimated concentration of chemical vapors within the worker's breathing zone. The model estimates the amount of chemical inhaled by a worker during an activity in which the chemical has volatilized and the airborne concentration of the chemical vapor is estimated as a function of the source vapor generation rate ($Q_{vapor\_generation}$). This generation rate may be calculated using an appropriate standard EPA vapor generation model (see Equation B-1, Equation B-3, or Equation B-5) or may be an otherwise known value.

The *EPA/OPPT Mass Balance Model* also utilizes the volumetric ventilation rate within a given space and includes simplifying assumptions of steady state (i.e., a constant vapor generation rate and a constant ventilation rate) and an assumed mixing factor for non-ideal mixing of air. The default ventilation rates and mixing factors provide a typical and worst case estimate for each exposure. The airborne concentration of the chemical cannot exceed the level of saturation for the chemical.

An evaluation of the model was performed against collected monitoring data for various activities (see the 1996 AIHA article). This evaluation confirmed that the Mass Balance Model is able to conservatively predict worker inhalation exposures within one order of magnitude of actual monitoring data and is an appropriate model for screening-level estimates.

Model Equations:

The model first calculates the volumetric concentration of the chemical vapor in air using the following equation:

$$C_{chem\_volumetric} = \frac{(1.7 \times 10^5) \times TEMP_{ambient} \times Q_{vapor\_generation}}{MW_{chem} \times RATE\overset{\rightleftharpoons}{}_{ventilation} \times F_{mixing\_factor}} \qquad [B-7]$$

Where:

$C_{chem\_volumetric}$	=	Volumetric concentration of the chemical vapor in air (ppm)
$Q_{vapor\_generation}$	=	Average vapor generation rate (g of chemical/sec; see Equation B-1, Equation B-3, or Equation B-5, as appropriate)
$TEMP_{ambient}$	=	Ambient temperature (EPA default = 298 K)
MW_{chem}	=	Molecular weight of the chemical of interest (g/mol)

RATE$_{ventilation}$ = Ventilation rate (ft^3/min; see Table B-2 for appropriate EPA default values)

F$_{mixing\_factor}$ = Mixing factor (dimensionless; see Table B-2 for appropriate EPA default values)

Note: The factor 1.7×10^5 in Equation B-7 accounts for various unit conversions. See Fehrenbacher and Hummel, 1996, for the derivation of this constant.

Note that the airborne concentration of the chemical vapor cannot exceed the saturation level of the chemical in air. Equation B-8 calculates the volumetric concentration at the saturation level based on Raoult's Law. Use the lesser value for the volumetric concentration of the chemical vapor (C$_{chem\_volumetric}$) calculated in either Equation B-7 or Equation B-8 in calculating the mass concentration of the chemical of interest in the air (see Equation B-9).

$$C_{\text{chem\_volumetric}} = F_{\text{correction\_factor}} \times VP_{\text{chem}} \times \frac{10^6 \text{ ppm}}{P_{\text{ambient}}}$$ [B-8]

Where:

C$_{chem\_volumetric}$ = Volumetric concentration of the chemical of interest in air (ppm)

F$_{correction\_factor}$ = Vapor pressure correction factor (EPA default =1)[1]

VP$_{chem}$ = Vapor pressure of the chemical of interest (torr)

P$_{ambient}$ = Ambient pressure (Default = 760 torr)

Note: Raoult's law calculates the airborne concentration as a mole fraction. The factor 10^6 in Equation B-8 accounts for the unit conversion from mole fraction to ppm.

The volumetric concentration of the chemical of interest in air (calculated in either Equation B-7 or Equation B-8) is converted to a mass concentration by the following equation:

$$C_{c\square em\_mass} = \frac{C_{c\square em\_volumetric} \times MW_{c\square em}}{V_{molar}}$$ [B-9]

Where:

C$_{chem\_mass}$ = Mass concentration of the chemical vapor in air (mg/m^3)

C$_{chem\_volumetric}$ = Volumetric concentration of the chemical vapor in air (ppm, see Equation B-7 or B-8, as appropriate)

---

[1]The default vapor pressure correction factor, F$_{correction\_factor}$, assumes that the chemical-containing material in the evaporating pool exhibits the vapor pressure of the chemical of interest, as a worst case (i.e., effective VP of the evaporating material = F$_{correction\_factor}$ × VP$_{chem}$). Alternatively, Raoult's Law may be assumed (i.e., effective VP = mole fraction of the chemical in the material × VP$_{chem}$), thus the F$_{correction\_factor}$ may be set equivalent to the chemical's mole fraction in the material, if known. Note: in the absence of more detailed data, the chemical's weight fraction within the material formulation may be used to approximate its mole fraction.

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MW_{chem} = Molecular weight of the chemical of interest (g/mol)

V_{molar} = Molar volume (Default = 24.45 L/mol at 25°C and 1 atm)

Assuming a constant breathing rate for each worker and an exposure duration for the activity, the inhalation exposure to the chemical vapor during that activity can be estimated using the following equation:

$$EXP_{inhalation} = C_{chem\_mass} \times RATE_{breathing} \times TIME_{exposure} \qquad [B\text{-}10]$$

Where:

$EXP_{inhalation}$ = Inhalation exposure to the chemical vapor per day (mg chemical/worker-day)

C_{chem_mass} = Mass concentration of the chemical vapor in air (mg/m³; see Equation B-9]

$RATE_{breathing}$ = Typical worker breathing rate (EPA default = 1.25 m³/hr)

$TIME_{exposure}$ = Duration of exposure for the activity (hours/worker-day; see Table B-2 for appropriate EPA default values ($\leq$ 8 hours/worker-day))

References:

Fehrenbacher, M.C. and Hummel, A.A[1]. "Evaluation of the Mass Balance Model Used by the EPA for Estimating Inhalation Exposure to New Chemical Substances". *American Industrial Hygiene Association Journal.* June 1996. 57: 526-536.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1 (Equation 4-21). U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

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[1]Note: This reference is currently not available for viewing in the ChemSTEER Help System.

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Table B-2. Standard EPA Default Values Used in the *EPA/OPPT Mass Balance Inhalation* Model

Activity Type (Location)	V_{cont_empty} (gallons)	$RATE_{fill}$ (containers/hour)	$RATE_{air\_speed}$ (feet/min)	$RATE_{ventilation}$ [a]	$F_{mixing\_}$
Container-Related Activities (e.g., filling, unloading, cleaning, open surface/evaporative losses):					
Bottles (Indoors)	1 Range: <5	60	100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical Worst Ca
Small Containers (Indoors)	5 Range: 5 to <20				
Drums (Indoors)	55 Range: 20 to <100	20			
Totes (Indoors)	550 Range: 100 to <1,000				
Tank Trucks (Outdoors)	5,000 Range: 1,000 to <10,000	2	440 (Outdoors)	Average: 237,600 Worst Case: $26,400 \times (60 \times RATE_{air\_speed}) 5,280)^3$ (Outdoors)	
Rail Car (Outdoors)	20,000 Range: 10,000 and up	1			
Equipment Cleaning Activities:					
Multiple Vessels (Outdoors)	Not applicable		440 (Outdoors)	Average: 237,600	Typical Worst Ca
Single, Large Vessel (Outdoors)					

Activity Type (Location)	V_{cont_empty} (gallons)	$RATE_{fill}$ (containers/hour)	$RATE_{air\_speed}$ (feet/min)	$RATE_{ventilation}$ [a]	$F_{mixing\_}$
Single, Small Vessel (Outdoors)				Worst Case: $26,400 \times$ $(60 \times RATE_{air\_speed}) 5,280)^3$ (Outdoors)	
Sampling Activities:					
Sampling Liquids (Indoors)	Not applicable	100 (Indoors)	Typical: 3,000 Worst Case: 500 (Indoors)	Typical Worst Ca
Other Activities:					
Continuous Operation Batch Operation	If other scenario-specific activities are identified that use one of the vapor generation rate models with the *Mass Balance Inhalation Model* described in this section, the ESD will describe the models and provide appropriate default values for the model parameters.				Typical Worst Ca

a - If the appropriate vapor generation rate model is the *EPA/OAQPS AP-42 Loading Model* (see Equation B-5) for an <u>outdoor</u> activity, the $RATE_{air\_speed}$ should be set to 440 feet/min, as a default in determining the worst case $RATE_{ventilation}$.

B.3. CONTAINER RESIDUE RELEASE MODELS (NON-AIR)

Model Description and Rationale:

EPA has developed a series of standard models for estimating the quantity of residual chemical remaining in emptied shipping containers that is released to non-air media (e.g., water, incineration, or landfill) when the container is either rinsed or disposed. All of the residue models assume a certain portion or fraction of the chemical remains in the emptied container to be later rinsed or discarded with the empty container.

The default parameters of model are defined based upon the particular size/type of container (e.g., small containers, drums, or large bulk), as well as the physical form of the chemical residue (e.g., liquid or solid). These defaults are based upon data collected during a 1988 EPA-sponsored study of residuals in containers from which materials have been poured or pumped.

Model Equation:

All of the models discussed in this section utilize the following common equation for calculating the amount of chemical residue:

$$\text{Elocal}_{container\_residue\_disp} = F_{container\_residue} \times Q_{total\_daily\_container} \qquad \text{[B-11]}$$

Where:

$\text{Elocal}_{container\_residue\_disp}$ = Daily release of the chemical residue to water, incineration, or landfill from the cleaning or disposal of empty shipping containers (kg/site-day)

$F_{container\_residue}$ = Fraction of the amount of the total chemical in the shipping container remaining in the emptied container (dimensionless; see Table B-1 for appropriate EPA default values)

$Q_{total\_daily\_container}$ = Total (daily) quantity of the chemical contained in the shipping containers prior to emptying (kg of chemical/site-day; see Table B-2 for appropriate EPA default values)

Each model, however, utilizes unique default values within that equation based upon the relative size of the container and the physical form of the chemical residue. These default values are summarized in Table B-1 and Table B-2. The following models are the standard EPA models for estimating container residues:

∞ *EPA/OPPT Small Container Residual Model*;
∞ *EPA/OPPT Drum Residual Model*;
∞ *EPA/OPPT Bulk Transport Residual Model*; and

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∞ *EPA/OPPT Solid Residuals in Transport Containers Model.*

The default frequency with which the container residues are released ($TIME_{days\_container\_residue}$, days/site-year) must be appropriately "paired" with the total daily quantity of chemical contained in the containers ($Q_{total\_daily\_container}$) used in calculating the daily release. Thus, Table B-2 also contains the appropriate EPA default values for $TIME_{days\_container\_residue}$.

References:

U.S. EPA. Chemical Engineering Branch. Memorandum: *Standard Assumptions for PMN Assessments.* From the CEB Quality Panel to CEB Staff and Management. October 1992.

U.S. EPA. Office of Pesticides and Toxic Substances. *Releases During Cleaning of Equipment.* July 1988.

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Table B-3. Standard EPA Default Values for Use in the Container Residual Release Models

Chemical Form	Container Type	V_{cont_empty} (gallons)	Model Title
Liquid	Bottle	1 Range: <5	*EPA/OPPT Small Container Residual Model*
	Small Container	5 Range: 5 to <20	
	Drum	55 Range: 20 to <100	*EPA/OPPT Drum Residual Model*
	Tote	550 Range: 100 to <1,000	*EPA/OPPT Bulk Transport Residual Model*
	Tank Truck	5,000 Range: 1,000 to <10,000	
	Rail Car	20,000 Range: 10,000 and up	
Solid	Any	Any	*EPA/OPPT Solid Residuals in Transport Containers Mo*

a - These defaults are based on the 1988 EPA study investigating container residue and summarized in the 1992 internal EPA memorandum (see *References* in this section for the citations of these sources).

b - The 1992 EPA memorandum reference document contains the previous default of 0.04 for the high-end loss fraction ($F_{container\_residue}$) for the *Drum Residual Model*; however, this value was superseded by an internal policy decision in 2002. Per 40 CFR 261.7(b)(1) of the Resource Conservation and Recovery Act (RCRA), "a

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container or an inner liner removed from a container that has held any hazardous wastes, except waste that is a compressed gas or that is identified as an acute hazardous waste…is empty if…(ii) no more than 2.5 centimeters (1 inch) remain on the bottom of the container or liner or (iii)(A) no more than 3 percent by weight of the total capacity of the container remains in the container or inner liner if the container is equal to or less than 110 gallons in size…". The 3 percent high-end default is consistent with the range of experimental results documented in the 1988 EPA study (see *References* in this section for a citation of this study).

Table B-4. Standard EPA Methodology for Calculating Default $Q_{total\_daily\_container}$ and $TIME_{days\_container\_residue}$ Values for Use in the Container Residual Models

Number of Containers Emptied per Day	$Q_{total\_daily\_container}$ (kg/site-day)	TIME (
1 or more	(Mass quantity of chemical in each container (kg/container)) × (Number of containers emptied per day)	Total number of operating
Less than 1	Mass quantity of chemical in each container (kg/container)	Total number of container

B.4. DERMAL EXPOSURE MODELS

Model Description and Rationale:

EPA has developed a series of standard models for estimating worker dermal exposures to liquid and solid chemicals during various types of activities. All of these dermal exposure models assume a specific surface area of the skin that is contacted by a material containing the chemical of interest, as well as a specific surface density of that material in estimating the dermal exposure. The models also assume *no use of controls or gloves* to reduce the exposure. These assumptions and default parameters are defined based on the nature of the exposure (e.g., one hand or two hand, immersion in material, contact with surfaces) and are documented in the references listed in this section.

In the absence of data, the EPA/OPPT standard models for estimating dermal exposures from industrial activities described in this section can be used. The models for exposures to liquid materials are based on experimental data with liquids of varying viscosity and the amount of exposure to hands was measured for various types of contact. Similar assessments were made based on experimental data from exposure to solids.

Model Equation:

All of the standard EPA models utilize the following common equation for calculating worker dermal exposures:

$$\text{EXP}_{\text{dermal}} = \text{AREA}_{\text{surface}} \times Q_{\text{remain\_skin}} \times F_{\text{chem}} \times N_{\text{event}} \qquad \text{[B-12]}$$

Where:

$\text{EXP}_{\text{dermal}}$ = Dermal exposure to the liquid or solid chemical per day (mg chemical/worker-day)

$\text{AREA}_{\text{surface}}$ = Surface area of the skin that is in contact with liquid or solid material containing the chemical (cm^2; see Table B-2 for appropriate EPA default values)

$Q_{\text{remain\_skin}}$ = Quantity of the liquid or solid material containing the chemical that remains on the skin after contact (mg/cm^2-event; see Table B-2 for appropriate EPA default values)

F_{chem} = Weight fraction of the chemical of interest in the material being handled in the activity (dimensionless; refer to the ESD discussion for guidance on appropriate default value)

N_{event}[1] = Frequency of events for the activity (EPA default = 1 event/worker-day)

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[1]Only one contact per day (N_{event} = 1 event/worker-day) is assumed because $Q_{\text{remain\_skin}}$, with few exceptions, is not expected to be significantly affected either by wiping excess chemical material from skin or by repeated contacts with additional chemical material (i.e., wiping excess from the skin does not remove a significant fraction of the small layer of chemical material adhering to

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Each model, however, utilizes unique default values within that equation based upon the nature of the contact and the physical form of the chemical material. These default values are summarized in Table B-9. The following models are the standard EPA models for estimating worker dermal exposures:

∞ *EPA/OPPT 1-Hand Dermal Contact with Liquid Model*;
∞ *EPA/OPPT 2-Hand Dermal Contact with Liquid Model*;
∞ *EPA/OPPT 2-Hand Dermal Immersion in Liquid Model*;
∞ *EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model*; and
∞ *EPA/OPPT 2-Hand Dermal Contact with Solids Model*.

For several categories of exposure, EPA uses qualitative assessments to estimate dermal exposure. Table B-5 summarizes these categories and the resulting qualitative dermal exposure assessments.

References:

U.S. EPA. Chemical Engineering Branch. *Options for Revising CEB's Method for Screening-Level Estimates of Dermal Exposure – Final Report*. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. June 2000.

U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

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the skin and additional contacts with the chemical material do not add a significant fraction to the layer). Exceptions to this assumption may be considered for chemicals with high volatility and/or with very high rates of absorption into the skin.

Table B-5. Standard EPA Default Values for Use in the Worker Dermal Exposure Models

Default Model	Example Activities	$AREA_{surface}$[a] (cm²)	Q_{remain_skin}[b] (mg/cm²-event)	Resulting Contact $AREA_{surface} \times Q_{remain\_skin}$ (mg/event)
Physical Form: Liquids				
EPA/OPPT 1-Hand Dermal Contact with Liquid Model	∞ Liquid sampling activities ∞ Ladling liquid/bench-scale liquid transfer	535 (1 hand mean)	Low: 0.7 High: 2.1	Low: 380 High: 1,100
EPA/OPPT 2-Hand Dermal Contact with Liquid Model	∝ Maintenance ∞ Manual cleaning of equipment and containers ∞ Filling drum with liquid ∞ Connecting transfer line	1,070 (2 hand mean)	Low: 0.7 High: 2.1	Low: 750 High: 2,200
EPA/OPPT 2-Hand Dermal Immersion in Liquid Model	∞ Handling wet surfaces ∞ Spray painting	1,070 (2 hand mean)	Low: 1.3 High: 10.3	Low: 1,100 High: 11,000
Physical Form: Solids				
EPA/OPPT 2-Hand Dermal Contact with Container Surfaces Model	∞ Handling bags of solid materials (closed or empty)	No defaults	No defaults	< 1,100[c]
EPA/OPPT 2-Hand Dermal Contact with Solids Model	∝ Solid sampling activities ∞ Filling/dumping containers of powders, flakes, granules ∞ Weighing powder/scooping/mixing (i.e., dye weighing) ∞ Cleaning solid residues from process equipment ∞ Handling wet or dried material in a filtration and drying process	No defaults	No defaults	< 3,100[23]

a - These default values were adopted in the 2013 EPA updates on screening-level dermal exposure estimates (USEPA, 2013) and are the mean values for men taken from the EPA Exposure Factors Handbook, 2011.

b - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived the selected ranges of values for liquid handling activities from: U.S. EPA. A Laboratory Method to Determine the Retention of Liquids on the Surface of Hands. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Exposure Evaluation Division. EPA 747-R-92-003. September 1992.

c - These default values were adopted in the 2000 EPA report on screening-level dermal exposure estimates (see *References* in this section for the citation of this source). The report derived values for dermal contact for solids handling activities from: Lansink, C.J.M., M.S.C. Breelen, J. Marquart, and J.J. van Hemmen: Skin Exposure to Calcium Carbonate in the Paint Industry. Preliminary Modeling of

Skin Exposure Levels to Powders Based on Field Data (TNO Report V 96.064). Rijswijk, The Netherlands: TNO Nutrition and Food Research Institute, 1996.

**Table B-6. EPA Default Qualitative Assessments for Screening-Level Estimates of
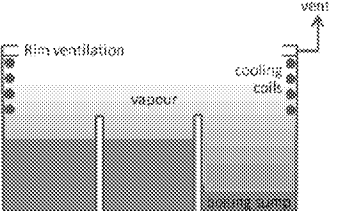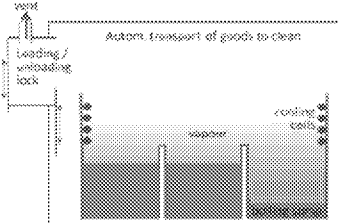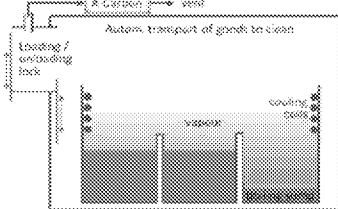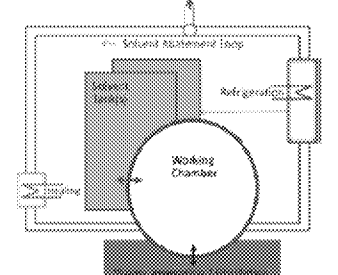Dermal Exposure**

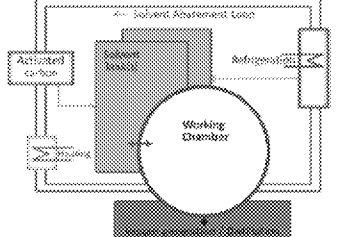| Category	Dermal Assessment
Corrosive substances (pH>12, pH<2)	Negligible
Materials at temperatures >140)F (60)C)	Negligible
Cast Solids (e.g., molded plastic parts, extruded pellets	Non-Quantifiable (Some surface contact may occur if manually transferred)
"Dry" surface coatings (e.g., fiber spin finishes, dried paint)	Non-Quantifiable (If manual handling is necessary and there is an indication that the material may abrade from the surface, quantify contact with fingers/palms as appropriate)
Gases/Vapors	Non-Quantifiable (Some contact may occur in the absence of protective clothing)

Source: U.S. EPA. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessment*, Volume 1. U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington DC. Contract No. 68-D8-0112. February 1991.

Appendix C: ECSA Classification for Surface Cleaning Machines

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The following provides ECSA classifications of surface cleaning machines, including vapor degreasers. The table describes the different machine types / generations, and the associated controls. ECSA recommends the use of Type III or higher machine for surface cleaning to minimize emissions and solvent use.

Table D-1. ECSA Classification of Surface Cleaning Machines

Current ECSA Nomenclature	Schematic Drawing	Key Characteristic
Type I Open Top		• Open top • Rim ventilation • Cooling with water or refrigerated cooling (2°C) Typical air emission: 1-16kg/hr (avg. 4.7 kg/hr)
Type IIa Enclosed (vented directly to atmosphere)		• Encased (all sides closed) • Vented air lock for loading/unloading of goods • Refrigerated cooling • Automatic transport of goods Typical air emission: 2.0 kg/hr
Type IIb Enclosed & abatement (vented through external A-Carbon filter)		• As Type IIa but with additional external A-carbon filter for solvent abatement from exhaust air Typical air emission: 1.0 kg/hr
Type III Closed with internal air cleaning prior to opening		• Closed single chamber or use of a collection chamber (air-lock to seal against solvent bathe(s)) • Solvent abatement loop with refrigeration (<-20°C) to clean air prior to opening (<2g/m^2) Typical air emission: 155 g/hr
Type IV Closed with closed loop air drying without vent		• No exhaust air (fully closed air loops) • Equipm. Internal A-carbon in addition to refrigeration • Better drying also of goods with difficult shapes Typical air emission: 1-100 g/hr, average ~38 g/hr

Current ECSA Nomenclature	Schematic Drawing	Key Characteristic
Type V Closed without vent and operation under vacuum		• As type IV but with vacuum technology, keeping the working chamber and distillation under reduced pressure during operation • Improved drying • Reduced emissions • Reduced waste • Increased solvent life time (because of lower temperature)

Source: (ECSA, 2013)

APPENDIX D: APPROACH FOR ESTIMATING NUMBER OF WORKERS

This appendix summarizes the methods that EPA/OPPT used to estimate number of workers who are potentially exposed to chemicals used in degreasing applications. The method consists of the following steps:

1. Identify the North American Industry Classification System (NAICS) codes for the industry sectors associated with these uses.
2. Estimate total employment by industry/occupation combination using the Bureau of Labor Statistics' Occupational Employment Statistics (OES) data (BLS, 2016).
3. Refine the OES estimates where they are not sufficiently granular by using the U.S. Census' Statistics of US Businesses (SUSB) (2015) data on total employment by 6-digit NAICS.
4. Combine the data generated in Steps 1 through 3 to produce an estimate of the number of establishments and employees that may come into contact with the degreasing chemical in each industry/occupation combination, and sum these to arrive at a total estimate of the number of employees with exposure.

Step 1: Identify Affected NAICS Codes

As a first step, EPA/OPPT identified NAICS industry codes associated with the uses in the scope. EPA/OPPT referenced EPA's Trichloroethylene (TCE) risk assessment, in which EPA/OPPT has identified a list of all possible NAICS industry sectors that may have degreasing operations (U.S. EPA, 2014). It should be noted that degreasing encompasses a large number of industry sectors, and not all facilities in the identified NAICS code will have a degreasing operation.

Table F-1 lists the 6-digit NAICS code associated with degreasing applications. In addition, the table lists the corresponding BLS NAICS code at the 4-digit or 5-digit level. Note BLS employment data for certain sectors are only available at the 4-digit or 5-digit NAICS level (see Step 3 for refinement of BLS data).

Table F-1. NAICS Codes for Degreasing Uses

NAICS	BLS NAICS	Industry
314999	314900	All Other Miscellaneous Textile Product Mills
321113	321100	Sawmills
323111	323100	Commercial Printing (except Screen and Books)
325180	325100	Other Basic Inorganic Chemical Manufacturing
325998	325900	All Other Miscellaneous Chemical Product and Preparation Manufacturing
326299	326200	All Other Rubber Product Manufacturing

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NAICS	BLS NAICS	Industry
331110	331100	Iron and Steel Mills and Ferroalloy Manufacturing
331210	331200	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
331410	331400	Nonferrous Metal (except Aluminum) Smelting and Refining
331420	331400	Copper Rolling, Drawing, Extruding, and Alloying
332111	332100	Iron and Steel Forging
332112	332100	Nonferrous Forging
332119	332100	Metal Crown, Closure, and Other Metal Stamping (except Automotive)
332117	332100	Powder Metallurgy Part Manufacturing
332215	332200	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing
332216	332200	Saw Blade and Handtool Manufacturing
332311	332300	Prefabricated Metal Building and Component Manufacturing
332313	332300	Plate Work Manufacturing
332431	332400	Metal Can Manufacturing
332510	332500	Hardware Manufacturing
332618	332600	Other Fabricated Wire Product Manufacturing
332721	332720	Precision Turned Product Manufacturing
332722	332720	Bolt, Nut, Screw, Rivet, and Washer Manufacturing
332811	332800	Metal Heat Treating
332812	332800	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers
332813	332800	Electroplating, Plating, Polishing, Anodizing, and Coloring
332912	332900	Fluid Power Valve and Hose Fitting Manufacturing
332913	332900	Plumbing Fixture Fitting and Trim Manufacturing
332919	332900	Other Metal Valve and Pipe Fitting Manufacturing
332994	332900	Small Arms, Ordnance, and Ordnance Accessories Manufacturing
332996	332900	Fabricated Pipe and Pipe Fitting Manufacturing
332999	332900	All Other Miscellaneous Fabricated Metal Product Manufacturing

NAICS	BLS NAICS	Industry
333132	333100	Oil and Gas Field Machinery and Equipment Manufacturing
333249	333200	Other Industrial Machinery Manufacturing
333318	333300	Other Commercial and Service Industry Machinery Manufacturing
333410	333400	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing
333415	333400	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing
333921	333900	Elevator and Moving Stairway Manufacturing
333994	333900	Industrial Process Furnace and Oven Manufacturing
333999	333900	All Other Miscellaneous General Purpose Machinery Manufacturing
334220	334200	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing
334413	334400	Semiconductor and Related Device Manufacturing
334416	334400	Capacitor, Resistor, Coil, Transformer, and Other Inductor Manufacturing
334417	334400	Electronic Connector Manufacturing
334419	334400	Other Electronic Component Manufacturing
334513	334500	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
334515	334500	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
335120	335100	Lighting Fixture Manufacturing
335121	335100	Residential Electric Lighting Fixture Manufacturing
335210	335200	Small Electrical Appliance Manufacturing
335310	335300	Electrical Equipment Manufacturing
335312	335300	Motor and Generator Manufacturing
335313	335300	Switchgear and Switchboard Apparatus Manufacturing
335911	335900	Storage Battery Manufacturing
335921	335900	Fiber Optic Cable Manufacturing
335929	335900	Other Communication and Energy Wire Manufacturing
335999	335900	All Other Miscellaneous Electrical Equipment and Component Manufacturing

NAICS	BLS NAICS	Industry
336320	336300	Motor Vehicle Electrical and Electronic Equipment Manufacturing
336340	336300	Motor Vehicle Brake System Manufacturing
336410	336400	Aerospace Product and Parts Manufacturing
336411	336400	Aircraft Manufacturing
336413	336400	Other Aircraft Parts and Auxiliary Equipment Manufacturing
336414	336400	Guided Missile and Space Vehicle Manufacturing
336510	336500	Railroad Rolling Stock Manufacturing
337125	337120	Household Furniture (except Wood and Metal) Manufacturing
337127	337120	Institutional Furniture Manufacturing
339114	339100	Dental Equipment and Supplies Manufacturing
339990	339900	All Other Miscellaneous Manufacturing
339992	339900	Musical Instrument Manufacturing
339995	339900	Burial Casket Manufacturing
339999	339900	All Other Miscellaneous Manufacturing
488111	488100	Air Traffic Control
493110	493100	General Warehousing and Storage
811310	811300	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance

Step 2: Estimating Total Employment by Industry and Occupation

BLS's OES data (2016) provide employment data for workers in specific industries and occupations. The industries are classified by NAICS codes (identified previously), and occupations are classified by Standard Occupational Classification (SOC) codes.

Among the relevant NAICS codes (identified previously), EPA/OPPT reviewed the occupation description and identified those occupations (SOC codes) where workers may potentially come into contact with the degreasing chemical. Table F-2 shows several example SOC codes. EPA/OPPT classified the SOC codes into "workers (W)" (near-field exposure) and "Occupational Non-User (ONU)" (far-field exposure), where possible.

Table F-2. SOC Codes with Possible Exposure to Degreasing Chemicals

Application	SOC	Occupation	Designation
Vapor Degreasing	17-2000	Engineers	ONU
	17-3000	Drafters, Engineering Technicians, and Mapping Technicians	ONU
	19-4000	Life, Physical, and Social Science Technicians	ONU
	49-1000	Supervisors of Installation, Maintenance, and Repair Workers	ONU
	49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	W
	49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	W
	49-9010	Control and Valve Installers and Repairers	W
	49-9020	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	W
	49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	W
	49-9060	Precision Instrument and Equipment Repairers	W
	49-9070	Maintenance and Repair Workers, General	W
	49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	W
	51-1000	Supervisors of Production Workers	ONU
	51-2000	Assemblers and Fabricators	W
	51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	W

After identifying relevant NAICS and SOC codes, EPA/OPPT used BLS data to determine total employment by industry and by occupation based on the NAICS and SOC combinations. For example, there are 13,560 employees associated with 4-digit NAICS 333200 (*Industrial Machinery Manufacturing*) and SOC 51-2000 (*Assemblers and Fabricators*).

Using a combination of NAICS and SOC codes to estimate total employment provides more accurate estimates for the number of workers than using NAICS codes alone. Using only NAICS codes to estimate number of workers typically result in a gross overestimate, because not all workers employed in that industry sector will be exposed. However, note in some cases, BLS only provide employment data at the 4-digit or 5-digit NAICS level; therefore, further refinement of this approach may be needed (see next step).

Step 3: Refining Employment Estimates to Account for Lack of NAICS Granularity

The third step in EPA/OPPT's methodology was to further refine the employment estimates by using total employment data in the U.S. Census' SUSB (2015). In some cases, BLS OES's occupation-specific data are only available at the 4-digit or 5-digit NAICS level, whereas the SUSB data are available at the 6-digit level (but are not occupation-specific). Identifying specific 6-digit NAICS will ensure that only industries with potential exposure are included. For instance, OES data are available for the 4-digit NAICS 3332 *Industrial Machinery Manufacturing*, of which only the 6-digit NAICS 333249 *Other Industrial Machinery Manufacturing* is of interest. The Census data allow us to calculate employment in the specific 6-digit NAICS of interest as a percentage of employment in the BLS 4-digit NAICS.

Table F-3 and Table F-4 provide example calculations. NAICS 333249 makes up 48 percent of total employment under NAICS 3332. This percentage can be multiplied by the occupation-specific employment estimates given in the BLS OES data to further refine our estimates of the number of employees with potential exposure.

For example, the number of workers under NAICS 333249 is calculated as:

37,250 (*Employment in NAICS/SOC*) x 48% (*Granularity Adjustment Percentage*) = *17,870 workers* and *occupational non-users* under 6-digit NAICS 333249.

Table F-3. Sample Granularity Calculation

NAICS	Industry	Total Employment	Percent of Total Employment
4-Digit Parent NAICS			
3332	Industrial Machinery Manufacturing	97,475	100%
6-Digit NAICS Relevant to Vapor Degreasing			
333249	Other Industrial Machinery Manufacturing	46,762	48%

Source: U.S. Census Bureau (2014)

Table F-4. Estimated Number of Workers and Occupational Non-Users under NAICS 333249

NAICS	SOC CODE	SOC Description	Employment by SOC at 4-digit NAICS level	% of Total Employment	Estimated Employment by SOC at 6-digit NAICS level
333200	17-2000	Engineers	11,780	48.0%	5,651
	17-3000	Drafters, Engineering Technicians, and Mapping Technicians	3,810	48.0%	1,828
	19-4000	Life, Physical, and Social Science Technicians	60	48.0%	29
	49-1000	Supervisors of Installation, Maintenance, and Repair Workers	520	48.0%	249
	49-2000	Electrical and Electronic Equipment Mechanics, Installers, and Repairers	480	48.0%	230
	49-3000	Vehicle and Mobile Equipment Mechanics, Installers, and Repairers	30	48.0%	14
	49-9040	Industrial Machinery Installation, Repair, and Maintenance Workers	2,280	48.0%	1,094
	49-9070	Maintenance and Repair Workers, General	1,210	48.0%	580
	49-9090	Miscellaneous Installation, Maintenance, and Repair Workers	80	48.0%	38
	51-1000	Supervisors of Production Workers	3,410		1,636
	51-2000	Assemblers and Fabricators	13,560	48.0%	6,505
	51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	30	48.0%	14
Total			37,250		17,870

Sources: U.S. Census Bureau (2014) and U.S. BLS (2016).

Step 4: Final Worker Estimates

For the final estimates, EPA/OPPT calculated the total number of potentially exposed employees by summing the number of workers and occupational non-users in each affected industry/occupation combination, using the formula previously described in Step 3.

Employment in NAICS/SOC (Step 2) × Granularity Adjustment Percentage (Step 3) = Potentially Exposed Employees

The number of workers and occupational non-users can then be divided by the number of establishments to calculate the average number of workers and occupational non-users per site. There are a total of 713,732 workers and 436,783 occupational non-users at 109,966 establishments potentially exposed to vapor degreasing chemicals. On average, this translates to approximately 6 workers and 4 occupational non-users per site.